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THE MILLS SPECTROGRAPH OF THE LICK OBSERVATORY.

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IT has long been planned that the great light-gathering power of the 36-inch refractor should be utilized for the spectroscopic determination of stellar velocities in the line of sight. Professor Keeler secured measures of the velocities of *a* Boötis, *a* Tauri, and *a* Orionis by visual methods in 1890–91 in connection with his observations of nebulæ, and a few other measures were made in 1891 by Dr. Crew and myself. The difficult character of the observations soon became forcibly evident. Even with the powerful telescope at command, it was clear that the number of stellar spectra suitable for accurate visual measurement was very small. The questionable value of previous measures secured with small telescopes was of itself sufficient warning not to expect much from the visual method. The signal success obtained at Harvard College Observatory by the photographic processes of recording spectra, and later the remarkable advance in accuracy of velocity determinations resulting from the employment of the photographic method at Potsdam, strongly discouraged further attempts to carry on the work visually.

The original star spectroscope of the Lick Observatory, though admirable for visual work, was not adapted to photo-

graphic observations on account of its great flexure even during short exposures. It was hoped to determine velocities by using a powerful Rowland plane grating, and several star spectra were thus photographed; but flexure in the framework of the instrument ruined the definition, and the attempt was abandoned.[1] Nevertheless, the instrument was used for photographing the prismatic spectra of nebulæ, new stars, Wolf-Rayet stars, etc., with more or less success. The experience thus gained was very useful in designing a new instrument suitable for efficient spectrographic work.

Thanks to the generosity of D. O. Mills, Esq., Professor Holden was able to provide the Lick Observatory with a spectrograph suitable for velocity determinations. It is now in regular use, and results of great accuracy are being obtained rapidly. It may be of value to describe the instrument and the methods of observation and reduction employed.

In designing the instrument, my constant effort was to adapt it to the determination of stellar velocities, utilizing the $H\gamma$ region of the spectrum. All other considerations were sacrificed if they in any way seemed to interfere with its efficiency or convenience for that line of work. Nevertheless, many of its features remain such that it can be converted easily and cheaply into a so-called universal spectroscope.

A large telescope has a great advantage in light-gathering power. It likewise has its own peculiar difficulties to be overcome. It might seem at first thought that a well-designed spectrograph of ordinary dimensions would be equally efficient with all telescopes whose angular apertures were equal to that of the collimator lens: in other words, that an instrument suitably designed for use on a telescope of 12 inches aperture and 19.3 feet focus, would be an efficient instrument in connection with a

[1] Judging from my experiments on the subject, the prospect is very promising for securing accurate velocity determinations of the brighter stars by means of diffraction gratings in combination with powerful telescopes. The principal difficulty to be overcome does not arise from flexure, but from the mounting of the grating. The problem of maintaining the reflection grating in position is analogous to securing the mirror of a reflecting telescope so that it cannot move, and yet be uncramped.

telescope of 36 inches aperture and 58 feet focus. But such is not necessarily the case. When our atmospheric conditions are excellent, the focal images of a star are substantially of the same size in both telescopes, and the same linear width of slit suffices for efficiency in the two cases. But the instrument must also be efficient under *average* atmospheric conditions. Now in average seeing the larger telescope forms a larger image of a star than the smaller telescope does. In order to utilize the same proportion of the light in each case, it is clear that the slit-width must be greater for the larger telescope than for the small. Therefore, to preserve the purity, the larger telescope requires the longer collimator. The length of collimator in this instrument was limited only by the size of the prisms which I thought it advisable to employ. It was decided to use a train of three dense flint prisms of such a size that they would properly receive from the collimator a circular beam of $H\gamma$ light $37^{mm}.4$ in diameter (about $1\frac{1}{2}$ inches), and of such a density and angle that they would deviate it about 180°. The corresponding length of collimator would be 724^{mm} (about $28\frac{1}{2}$ inches).

After the instrument arrived, I placed the slit in the focus of the collimator lens by Schuster's method, and measured the focal length of the lens in the following manner. The collimator section was separated from the rest of the instrument. A small, sensitive plate, cut to the proper shape, was pressed against the wide-open slit. The object-glass was directed to the sky immediately west of the Pleiades, and that group of stars allowed to drift across the line of sight. The trail of 20 Tauri passed centrally through the slit aperture. The distances of six other trails from that of 20 Tauri were measured with a micrometer. The focal length was computed from the formula

$$f=\frac{R-R_0}{\tan\,(\delta-\delta_0)}, \tag{1}$$

in which δ_0 is the apparent declination of 20 Tauri, R_0 the micrometer reading on that star's trail, and δ and R the corresponding quantities for each of the other stars. The focal lengths obtained were

From 18 Tauri	$f = 722^{mm}.3$
21 "	722 .8
28 "	722 .0
"	722 .5
27 "	722 .1
23 "	722 .7
	Mean $722^{mm}.4$

This is in close agreement with the specification dimension (28.5 inches $= 723^{mm}.9$) furnished Mr. Brashear.

The diameter of the object-glass of the great refractor is $91^{cm}.44$ (36 inches) and its focal length for $H\gamma$ rays is 1768^{cm} (58 feet). Whence it follows that the effective stellar aperture of the collimator lens is $37^{mm}.4$. The lens is double, of Jena glass, cemented, with clear aperture $44^{mm}.5$ stopped down to 38^{mm}.

The camera lens first used was a double one of Jena glass, cemented, of 16 inches focus. For reasons given in the sequel, it has been replaced by a triple lens.

Mr. Wright has, at my request, determined its focal length by means of star trails. He found

	$f = 406^{mm}.0$
	405 .0
Mean	$405^{mm}.5$

A second difficulty peculiar to a large refractor relates to the question of efficient guiding. A consideration of the color curve of the large object-glass will show the nature of the difficulty. The focal length is 48^{mm} greater for the $H\gamma$ rays than for the D rays, and the curve at $H\gamma$ is very steep. When the slit is placed in the $H\gamma$ focus the $H\gamma$ image is a point in the center of a large disk of light made up not only of the so-called visual rays, but also of the other blue rays. The central point cannot be clearly distinguished. It was feared that Dr. Huggins' simple method of guiding by means of reflecting-slit plates would not be efficient under these circumstances. Professor Vogel's method of viewing the slit by means of light reflected from the first prism surface would not answer: the image of a star in the

guiding telescope would be a long line with a slightly blue central portion. Guiding by means of a small diagonal telescope immediately in front of the plate would be satisfactory only in case it were inserted near the $H\gamma$ line. To insert the telescope at $H\gamma$ every few minutes would stop the exposure during the moments of guiding, and there would be more or less imperfect following between times. Likewise the danger of jarring the instrument, or of temperature changes from the proximity of the observer, would be objectionable. After numerous experiments I decided to utilize the light reflected from the first prism surface to form a guiding spectrum. The reflected light passes first through a 30° prism, and thence into the guiding telescope. The spectrum thus formed is, of course, not linear, but the region at $H\gamma$ is linear, since the $H\gamma$ rays are in focus on the slit. If the $H\gamma$ image is not in the slit there is a vacancy at $H\gamma$ in the guiding spectrum. An occulting bar in the eyepiece covers all the spectrum except the $H\gamma$ region. The light from this region alone is visible, and is easily kept at a maximum.[1]

Such, in brief, were the optical plans and dimensions adopted. The general specifications for the mounting were written by myself, though some of them were modified at Mr. Brashear's suggestion. Thus, while I desired to have the collimator enclosed in a trussed system of five inclined steel tubes, as in the Potsdam spectrograph, the number was reduced to four, for constructive reasons. Many of the parts which I desired to have of steel were constructed of brass and cast iron, on Mr. Brashear's advice, and the instrument seems to have suffered no loss thereby. The details of mechanical construction were largely left to Mr. Brashear to design.

I did not hesitate to adopt what seemed best in the applicable parts of existing spectroscopes. Many of the features are common to all instruments, and many were suggested to me by my experience of several years with imperfect spectrographs on the large telescope. A few of the features were suggested by

[1] A description of this method of guiding was published by me in 1895 — this JOURNAL, 2, 127— but is inserted here for completeness.

the Potsdam spectrograph, and many others by Professor Keeler's Allegheny spectroscope.

Three nights a week are devoted to spectroscopy with the great refractor, and the other nights to micrometer work, etc. It is therefore necessary to mount and dismount the spectrograph once a week. This gives rise to less inconvenience than might be expected, since everything is planned with that in view. The change from micrometer to spectrograph — and *vice versa* — is made by one person with ease and safety in six minutes. When the instrument is not in use it rests on its special case. This is provided with rubber-bound casters which dampen the jarring when the case is slowly moved. When the instrument is to be mounted on the telescope, the moving floor is brought to its highest level, and the telescope is pointed to hour angle zero and declination — 17½ degrees. This leaves the eyepiece about three feet above the floor, and the telescope makes an angle of 35 degrees with the horizon. The top of the spectrograph case is inclined at the same angle. The upper piece of the case is a strongly constructed framework supported on roller bearings. The framework can be moved lengthwise about three inches between guide rails by means of a lever. This movable framework carries the instrument. The lower space of the case is used for storage drawers and the Leyden jar, while the thermometer, Ruhmkorff coil and other pieces of apparatus are mounted on its sides. When the telescope has been made fast to a heavy safety weight on the floor, the micrometer weighing about 40 pounds, and a section of the telescope tailpiece weighing 85 pounds, are taken off. The spectrograph case is rolled up to the end of the telescope, and the observer, with one hand on the lever, forces the spectrograph into position, so that four lugs on the spectrograph pass over four bolts on the telescope, and, with the other hand, he screws on the four nuts. The removal of a 39-pound counter weight from the telescope completes the operation.

mounting

The end plate of the telescope is about 16 inches above the $H\gamma$ focus. It was necessary to design an extension of the tele-

scope reaching down to the point where the framework of the spectrograph must begin. This extension is left clamped to the spectrograph, but is not considered to be a part of the spectrograph. It is a part of the telescope, and remains with the spectrograph only for convenience. It consists of two circular cast iron plates, 18¾ and 12 inches in diameter, firmly joined by four inclined hollow steel tubes 1½ inches in diameter. Passing through the upper plate are four large steel screws which press against the end of the telescope and serve to collimate the instrument. The inclined rods carry the comparison apparatus for hydrogen and iron, and the lower end plate supports the electric switch board. Thus, none of the parts which require considerable handling are fixed to the spectrograph itself. The weight of this section, including the comparison apparatus, is 70 pounds, and its length is 21½ inches.

The spectrograph proper is attached to the upper section by four hinged clamps. The truss carrying the collimator consists of two brass end-plates 12 and 6¾ inches in diameter, and an intermediate web, all rigidly joined together by four inclined, hollow steel tubes 1¼ inches in diameter. The length of this truss is 23¼ inches. The tube which encases the collimator is securely fastened to the truss. The collimator as a whole is movable by rack and pinion in this tube through a range of 90^{mm}, and can be clamped at any desired reading of the millimeter scale with which it is furnished. The weight of the collimator section is forty-eight and one-half pounds.

The slit is similar to that of the original Lick Observatory spectroscope.[1] The jaws are opened and closed symmetrically with reference to the axis by means of a right and left screw whose pitch is $0^{mm}.2$. The milled head of the screw is divided to twenty parts, so that the slit-width corresponding to one division is $0^{mm}.02$. Immediately below the slit is a pair of jaws for varying the length of slit. They are moved symmetrically from or toward the center by a rack and pinion. Just behind these jaws is a diagonal eyepiece for viewing the slit. It moves

[1] Described by Professor Keeler in *Publications of the Lick Observatory*, 3, 174.

by a rack and pinion in a bearing-tube with perfect ease so that no undesirable strains are induced in the slit mechanism. As in Professor Keeler's Allegheny spectroscope, there is a thin wedge of brass mounted immediately in front of the center of the slit to protect the area on the plate occupied by the star spectrum while the comparison spectrum is photographing. An adjustable "stop" screw at the base of the wedge enables the observer to occult any desired central section of the slit. The slit apparatus as a whole is movable in the axis of the collimator by rack and pinion and can be clamped at any desired reading of a millimeter scale.

The comparison apparatus is well shown in the illustrations. The hydrogen tube is firmly mounted in the plane of the collimator axis and slit, and at an angle of 30° with the axis. An image lens of large angular aperture directs the light upon a 60° totally-reflecting prism, which sends it into the collimator. The iron electrodes and their image lens are mounted on a frame at one side of the cone of light from the object-glass. They are moved by rack and pinion into the collimator axis immediately in front of the slit when needed.

The prism box is built upon a strong brass bed-plate. One end of the plate is enlarged to the same size (six and three-fourths inches diameter) as the end-plate of the collimator truss. A turned ring on the end-plate fits neatly into a turned bearing in the prism-box plate to prevent lateral motion. The two plates are firmly held together by two strong capstan-headed clamping screws, very much as in the case of the Allegheny spectroscope. The other end of the prism-box plate receives the lower end of the camera, the camera projecting through the plate so as to bring the lens as close as possible to the third prism. The face-plates of the box are of sheet brass, held in position by brass webs, one bordering the bases of the prisms, and the other forming the curved outer face of the box.

The prisms are borne by strong mountings furnished with all necessary adjusting screws. They are pressed against their bed-plates by long, shallow springs which exert gentle pressures over

large areas of the prism ends. Each bed-plate is clamped by two strong thumbscrews to the adjacent face-plate of the prism box, and some additional support is lent by an abutting screw which passes through the opposite face-plate, and presses lightly upon the prism mounting. The 30° prism, which forms the guiding spectrum, is similarly mounted. There is no minimum deviation mechanism, as the instrument was designed for use in the $H\gamma$ region exclusively. The prisms are therefore adjusted to minimum deviation for $H\gamma$ and clamped. The weight of the prism box complete and guiding telescope is nineteen and one-half pounds.

The bearing surfaces at the lower end of the camera tube form a small section of a ball and socket joint. From exactly opposite points of it, small cylindrical rods project and rest in bearings which can be clamped. The whole camera can rotate about these rods through a small angle in the direction of the length of spectrum. The upper end of the camera is supported by two half-inch steel rods projecting out from the collimator truss. The camera can be moved to any desired position on these rods, and clamped. The outer end of the camera is provided with rack and pinion and millimeter scale for focusing, and with a shield for holding and clamping the brass plate holders. The aperture in the base of the shield, through which the light is admitted to the plate, is closed to exclude dust, when the instrument is not in use, by a thin brass slide which works in a groove. When the instrument is in use, the slide is drawn to one side and held by a spring-pin. The camera complete, two steel supporting rods, and one brass plate holder, weigh seven pounds.

Another camera, thirty-two inches long, is provided for the instrument. It is intended for use with the brighter stars which have fine lines in their spectra. It has not yet been tested, but will soon be brought into use.

The prism box and camera may be rotated 180° to the other side of the collimator truss. The collimator section is complete in itself, and may be rotated 180° on the upper section. The

upper section may be rotated through any angle along with the tail-piece of the telescope. It might occur that an instrument with a longer or shorter collimator would be desired for special purposes. Such an instrument could be attached at once to the present upper section, with the comparison apparatus ready for use.

The instrument was first used in May 1895, to determine the velocities in the system of Saturn. Excellent results were secured,[1] fully confirming the earlier results by Professor Keeler. The definition at the center of the field was excellent, but it was noticed that the plate holder required tipping through a large angle, in order to bring even a small range of spectrum into good focus. This was unexpected, as the lenses were ordered corrected for $H\gamma$. The adjustments were varied within all possible limits, without producing perceptible improvement. The difficulty seemed to lie in the lenses, and they were returned to Mr. Brashear for testing. The formulæ followed in their construction were confirmed by Professor Hastings. The lenses were examined by Mr. Brashear and tested by Professor Keeler, who found that they were properly corrected for $H\gamma$. When the lenses were returned I constructed considerable auxiliary apparatus to enable me to determine their color curves[2] by Schuster's method, using one prism.

The column "observed" in the following table contains the readings of the mm. scales resulting from several independent determinations of the foci. These were plotted with reference to the corresponding wave-lengths, and represented as well as possible by smooth curves, which furnish the numbers in the column "computed." The residuals, observed minus computed, are contained in the next column, followed by the corresponding "ordinates" to the color curve. The last two columns contain Professor Keeler's determination of the color curve of the camera lens when it was returned to Allegheny.

[1] See this JOURNAL, 2, 127–135.

[2] The original arrangement of the prism box did not permit this to be done.

Line	$722^{mm}.4$ collimator				$405^{mm}.5$ camera				$405^{mm}.5$ camera	
	Observed	Computed	O-C	Ordinates	Observed	Computed	O-C	Ordinates	O-C	Ordinates
$H\epsilon$	12.22	12.15	+.07	+0.14	14.17	14.10	+.07	+0.21	−.07	+0.13
$H\delta$	12.00	12.07	−.07	+0.06	13.94	13.98	−.04	+0.09	−.02	+0.05
λ 423 ...	12.10	12.03	+.07	+0.02	13.98	13.92	+.06	+0.03		
$H\gamma$	11.98	12.01	−.03	+0.00	13.86	13.89	−.03	0.00	.00	0.00
λ 447 ...	12.12	12.05	+.07	+0.04	13.96	13.93	+.03	+0.04		
λ 460 ...		12.13		+0.12		13.98		+0.09	+.12	+0.14
$H\beta$	12.3	12.37	−.07	+0.36	14.03	14.12	−.09	+0.23	−.03	+0.33
b_1	12.8	12.80	.00	+0.79	14.47	14.36	+.11	+0.47	+.17	+0.63
D	14.3	14.20	+.10	+2.19	15.16	15.10	+.06	+1.21	−.02	+1.35
$H\alpha$	15.3	15.45	−.15	+3.44	15.65	15.75	−.10	+1.86	.00	+2.10

Thus the color curves of the lenses were found to be correct, and the cause of the trouble remained a mystery. Could it lie in the prisms? If the surfaces were not flat, or if certain peculiarities of density prevailed, the prisms might act as under-corrected lenses and produce the observed effect. The prisms were removed from their mountings and the surfaces tested. They were found to be flat. In remounting the prisms I noticed that two of the shallow bent springs which press the prisms against their bases were too long. When the cross bars which hold them in position were forced home by the screws, the springs were unable to straighten, and therefore subjected the prisms to enormous pressure. Some improvement in the spectrum was noted when the springs were shortened, but the plates still required considerable tipping. I then tested the prisms separately in connection with the old spectroscope and found them satisfactory. I was then convinced that the difficulty lay in the camera lens. As the definition was satisfactory over the central 10^{mm} of the plate the work was allowed to proceed, and the velocities obtained were in excellent agreement.

The observed effects seemed to indicate that the color curve *at the center of the field* and the color curve *at some distance from the center* were very different. I tested the color curve with the eyepiece about 10^{mm} from the center of the field, and found that *the focal length for* λ 447 *was several mm. greater than for* λ 423.

The color curve was all right so long as the rays passed through the lens symmetrically with reference to the axis, but otherwise the curve was all wrong. The effect was practically the same with the lens reduced to one inch aperture. It had no field. Fearing that the angular aperture of the camera was too great for a double lens, I at once ordered a triple lens of Jena glass, cemented, of two inches clear aperture. That removed the difficulty. The definition is admirable over considerable range and the plate requires no tipping.

The prisms are slightly astigmatic; the focus for the dust lines is $0^{mm}.7$ longer than for the Fraunhofer lines. The astigmatism gives rise to no inconvenience, and in fact assists in distributing the light uniformly over the width of the spectrum. It is not affected by rotating the lenses and hence its cause lies in the prisms. With such dense prisms slight causes produce appreciable effects.

The average minimum deviations of the prisms, with the corresponding indices of refraction, computed from the well-known formula $n = \sin \frac{1}{2}(D+i) / \sin \frac{1}{2} i$, are

Line	D	$3D$	n
$H\epsilon$	61° 3′.3	183° 10′	1.7412
$H\delta$	60 21 .7	181 5	1.7352
$H\gamma$	59 20 .5	178 2	1.7263
$H\beta$	57 47 .2	173 22	1.7124

Assuming that Cauchy's formula

$$n = a + b\lambda^{-2} + c\lambda^{-4} \qquad (2)$$

expresses the relation between index of refraction and wave-length, I substituted the values of n and λ for the three lines $H\epsilon$, $H\gamma$ and $H\beta$, and solved for the values of a, b c. The resulting equation is

$$n = 1.67284 + [7.81165]\,\lambda^{-2} + [6.83031]\,\lambda^{-4}, \qquad (3)$$

in which the quantities between brackets are logarithms and the unit of wave-length is $\mu = 0^{mm}.001$. Lord Rayleigh's formula for the theoretical resolving power is

$$R = -(t_2 - t_1)\frac{dn}{d\lambda}, \tag{4}$$

where t_2 and t_1 are the longest and shortest paths of the light in the prisms. From (3) we have

$$\frac{dn}{d\lambda} = -[8.11268]\,\lambda^{-3} - [7.43237]\,\lambda^{-5}, \tag{5}$$

whose value at $H\gamma$ is -0.3342. The effective aperture of the collimator lens is $37^{mm}.4$ and the angle of incidence is $59° \ 20'$. Therefore $t_2 - t_1$ is 222^{mm}. Substituting these values in (4) we have

$$R = 74.2.$$

The corresponding expression for the purity is

$$P = \frac{\lambda}{d\psi + \lambda}\,R, \tag{6}$$

in which d is the width of slit and ψ the angular aperture of the collimator lens.

The width of slit assigned by the equation

$$\frac{d}{\text{Length of collimator}} = \frac{\lambda}{\text{Effective aperture of collimator}}$$

is $d = 0^{mm}.0084$. For this case $P = \frac{1}{2}\,R = 37.1$, and two monochromatic lines for which $\Delta\lambda = 0.117$ tenth-meters should be resolved. The matter was tested on the solar spectrum. The lines $\lambda\lambda$ 4348.003 and 4348.130, $\Delta\lambda = 0.127$ *t.m.*, were easily separated with slit-width $0^{mm}.0084$. They were just resolvable with slit-width $0^{mm}.012$, although the theoretical limit for that width is $\Delta\lambda = 0.142$ *t. m.*

At slit-width $0^{mm}.02$, $P = 21.9$ and $\Delta\lambda = 0.198$ *t.m.* The solar lines $\lambda\lambda$ 4320.907 and 4321.119, $\Delta\lambda = 0.212$ *t.m.*, stood well apart with $d = 0^{mm}.02$, and remained separated till d was increased to $0^{mm}.029$, although the corresponding theoretical limit is 0.261 *t.m.* For practicable slit-widths the observed purity was greater than its computed value.

The photographic resolution depends largely upon the character of the plates employed. Thus, in the solar spectrum, the limit of resolution with proper exposures on Eastman's lantern

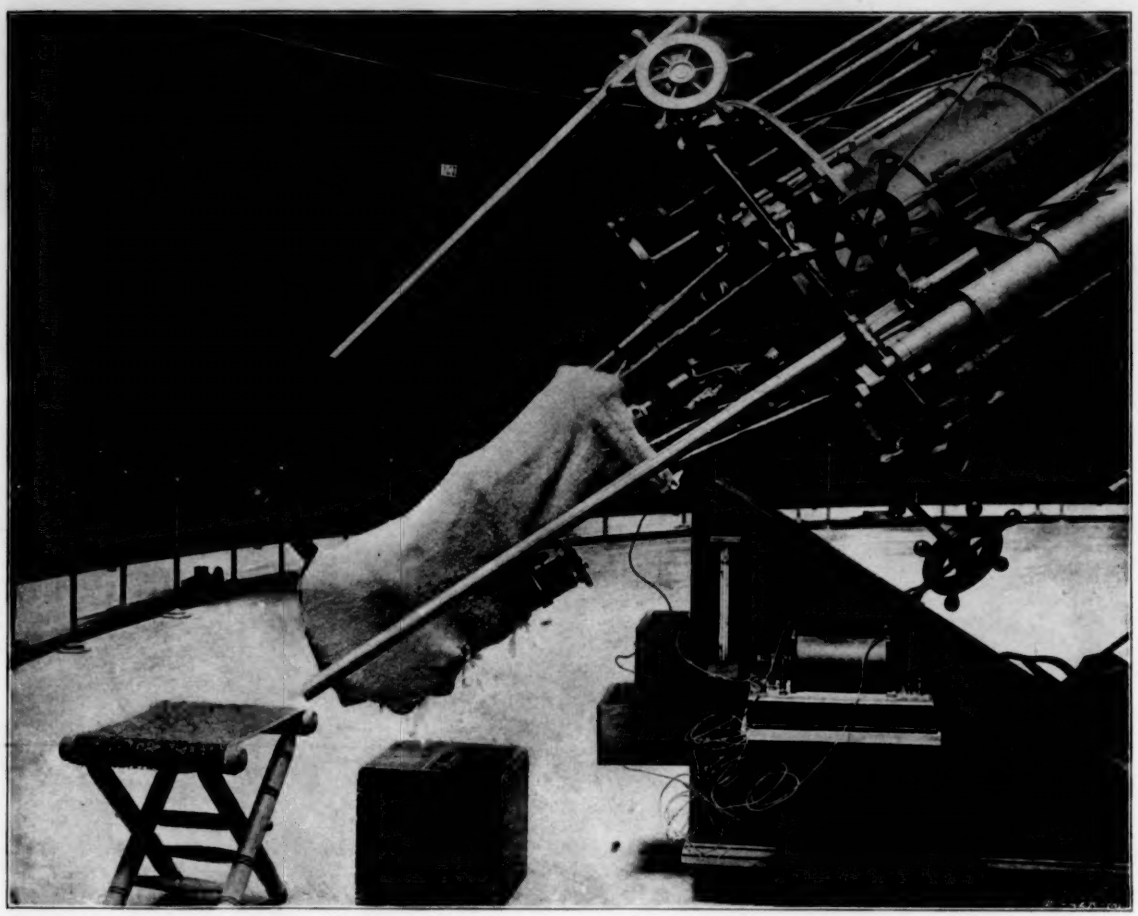
slide plates is about 0.15 *t. m.;* lines for which $\Delta\lambda = 0.20$ *t. m.* are rather widely separated. On rapid plates, with slit-width $0^{mm}.02$, a few negatives of stellar spectra show the lines $\lambda\lambda$ 4337.216 and 4337.414 to be separated. This is precisely the theoretical limit for $d = 0^{mm}.02$. With proper exposures, stellar lines for which $\Delta\lambda = 0.25$ *t. m.* are very often separated. I am unable to state the relation between diameters of the silver grains and photographic resolution. Much depends upon the exposure-time and the width of spectrum. It frequently happens that two close lines which unite at one point in a wide star spectrum are clearly separated at another.[1]

It is very unfortunate that the powerful modern spectrographs are so wasteful of light. The quantity of stellar light incident upon the object-glasses of great telescopes is sufficiently meager to start with, yet only a small fraction of the incident light succeeds in traversing the resisting media of modern spectrographs and recording itself upon the photographic plate. This is especially true for instruments photographing in the blue and violet, to which regions the line-of-sight work has practically all been confined. The question of economizing light already collected is as important as that of providing larger object-glasses, and merits the fullest consideration.

The prisms of the Mills spectrograph are slightly yellow, but may be called very clear considering their density. The average length of path which the light traverses in them is 120^{mm}. I have estimated, from the best available data, that about 50 per cent. of the $H\gamma$ light incident upon the first prism would be lost by absorption in passing through the three prisms. Again, computations show that about 40 per cent. of the light incident upon the first prism would be lost by reflection from the six prism surfaces. The combined loss due to absorption and reflection would be about 70 per cent.

[1] It would be interesting and profitable to compute the efficiency of the instrument according to Professor Wadsworth's formulae, but space is lacking, and my purpose has been simply to convey a general idea of the power of the instrument. The computations for various assumptions, and for lines of different character, can be made from the foregoing data.

PLATE IV.



THE MILLS SPECTROGRAPH AS USED IN MAKING OBSERVATIONS.

In order to test the matter, Mr. Wright and I have photographed a beam of $H\gamma$ light, first with the spectrograph complete, and second with the prism box removed. A graduated series of exposures, ranging from full exposure-time down to extreme under exposure, was made in each case, on plates exactly alike and equally developed. As nearly as could be estimated, the images in the two cases were of equal intensity when the series with the prism train was exposed four times as long as the series with the prism train eliminated. That is, roughly, 75 per cent. of the light was lost in traversing the prism train. Add to this the loss in the 36-inch object-glass, in the collimator and camera-lenses, to say nothing of the great loss at the slit, and it will be seen how small a proportion of the original beam of light is able to strike the sensitive plate.

The diameter of the central disk of a star in the focus of the 36-inch refractor given by the formula $d = 1.22\,\lambda\,/R$, in which R is the radius of the object-glass, is 0.24 second of arc for the $H\gamma$ image and $0''.31$ for the visual image. Practically, these dimensions are too large, since the outer edge of the disks is faint. The double-star observers with the telescope seem to experience no special difficulty in measuring fairly equal components, on first-class nights, when the components are $0''.13$ or more apart, even with the added disadvantage of strong chromatic aberration. The linear diameter of the $0''.24$ disk is $0^{mm}.020$, and that is possibly the limiting value of the slit-width in good seeing. Thus far I have used slit-widths from $0^{mm}.01$ to $0^{mm}.03$, depending on the brightness of the star and the state of the atmosphere.

The distance of the slit from the collimator lens is left unchanged, at scale reading 12.0. The reading of the camera scale is nearly independent of the temperature; the reading at $+30°$C. is only $0^{mm}.1$ greater than for $0°$C. The reading of the collimator scale for the slit in the focus of the large object-glass was determined by making a series of exposures on the spectrum of a bright star with the scale readings differing $0^{mm}.5$ from each other. The plate having been set in focus for the

dust lines, that one of the series which is linear at $H\gamma$ corresponded to the scale reading for which the $H\gamma$ image was in focus on the slit. Nineteen determinations of the scale reading were made between June 1896 and April 1897, with the temperature varying from $+2^\circ.4$ C. to $24^\circ.8$ C. The observations were well satisfied by an equation of the form

$$\text{Scale reading} = a\,t + b,$$

in which t is the reading of the centigrade thermometer, and a and b are constants. A least squares combination of the nineteen observations gave

$$\text{Scale reading} = 0.562\,t + 49.24,$$

with a probable error of a single observation equal to $\pm 0^{\text{mm}}.4$. The instrument is occasionally used in the winter at -5°C., and in the summer at $+25^\circ$C. The scale readings in the two cases are $46^{\text{mm}}.4$ and $63^{\text{mm}}.3$, differing 17^{mm}. In addition, the length of the steel telescope tube increases 6^{mm} when the temperature rises from -5° to $+25^\circ$. The focal length of the 36-inch object-glass is therefore 23^{mm} greater at the summer temperature than at the winter. Scale readings determined in this manner are liable to some uncertainty, inasmuch as the temperature of the object-glass may be quite different from that indicated by a thermometer near the floor. I endeavored, therefore, to secure the observations when the temperature had been constant for some time.

The image lenses for the hydrogen tube and iron spark have large angular apertures. The angular aperture of the collimator lens is 3°, whereas that of the hydrogen lens is 13°, and that of the iron lens 25°. At the beginning of each night's work the observer makes sure that the beam of $H\gamma$ light fills the collimator lens. This is readily done by placing the eye at the point where the image of the $H\gamma$ line is formed on the sensitive plate. If the hydrogen tube is correctly placed, the observer will see the completely illuminated circular image (apparently) on the camera lens. The effect of the prismatic absorption is shown in this image, the edge corresponding to the vertices of the prisms

being much brighter than the edge corresponding to their bases. The $H\gamma$ line is then observed in the camera by means of an eyepiece. The hydrogen tube is gently pressed first to one side and then to the other. If it disappears in both directions under equal pressures, it is considered to be in adjustment. The iron electrodes are usually 1^{mm} or more apart, placed at right angles to the slit length, so that the image of the spark on the slit is of considerable size. The illumination of the collimator lens by the artificial light has been thoroughly tested. Among other tests, the beam of emergent light was photographed on plates held against the end of the collimator tube. The resulting circular images were of uniform intensity throughout. This test did not apply at first, owing to the absence of diaphragms to cut off the light reflected from the collimator tube. Diaphragms have been inserted in both collimator and camera.

The exposure time for the comparison spectrum is usually about 5 seconds for the $H\gamma$ line, 3 seconds for the brightest iron lines, and 60 seconds for the faint iron lines. A simple device enables these exposures to be given. The thin brass slide immediately in front of the plate, already described, was adjusted to move with accuracy and ease. I filed the edge of it away so as to leave three projections: two narrow strips in positions to cover the bright iron lines $\lambda\lambda$ 4308 and 4326, and a broad strip in position to cover the region $\lambda\lambda$ 4380–4420, which contains the bright iron lines $\lambda\lambda$ 4384, 4405, and 4415. When the iron spectrum has been photographing three seconds, the occulting strips of brass are slipped (lengthwise) over the brightest five iron lines, and the exposure on the faint iron lines goes on to the end of the minute. The device is simple and safe.

Temp

The deviation by the prisms is affected by temperature changes. Before beginning a night's work the camera is unclamped and moved so that the lines $\lambda\lambda$ 4308 and 4326 are exactly central on their occulting strips.

The value of the temperature coefficient of the deviation is not known at present. Observations for that purpose, taken by Messrs. Wright and Cottrell, yield very discordant results,

apparently from the fact that the temperature changes of the prisms lag behind those of the air in the prism box much more than was anticipated and allowed for. We shall at once mount a delicate thermometer on the spectrograph, its bulb near the center of the prism box and its tube alongside the collimator tube. It will be used both to investigate the deviation coefficient and to indicate temperature changes during stellar spectrum exposures. The temperature heretofore has been noted at the beginning and end of each exposure from the thermometer attached to the spectrograph case.

The desirability of uniform temperature in spectrographic work is very great.[1] The definition and the deviation are both affected by that factor. The Lick Observatory is fortunately situated in this respect. The temperature generally varies less than 2° Centigrade from dark to dawn. I have observed on many nights when the variation from ten o'clock to daylight has been less than 1°. It is very seldom, after nine o'clock, that the thermometer readings in the dome change a half degree during exposures of an hour.

When I first used the spectrograph, the definition of the star spectra was sometimes inexplicably poor, even when the temperature was constant. I was inclined to attribute this to the heating of the prism box by the observer's breath and body. He necessarily sits very close to it while guiding. I covered the prism box with a closely fitting hood of two thicknesses of heavy gray woolen blanket. In addition, a double hood of the same material covers the whole instrument. The prism box is therefore protected by four thicknesses. An improvement in the definition was at once noted.

The exposure-time for the star spectra is necessarily a function of the brightness, atmospheric conditions, slit-width, and plate sensitiveness. Professor Pickering has published in the *Draper Catalogue* a column of "Magnitudes," containing estimates of the photographic intensities of the spectra in the vicinity of G. These estimates are my guide in assigning the

[1] See article by M. DESLANDRES in *Bulletin Astronomique*, February 1898.

exposure-times. If the seeing is fair, the spectrum of a star of *D. C.* magnitude 5.0 will photograph in one hour with slit-width $0^{mm}.025$. An exposure of 15 seconds and slit-width $0^{mm}.015$ will answer for *Sirius*. The spectra are made about $0^{mm}.3$ wide. 4 guiding

The illustration (Plate III) shows the apparatus ready for use. A wooden rod attached to the main telescope tube runs down to the observer's right hand. A slight pressure on this rod, to the right and left, enables him to judge of the guiding in right ascension. A slight pressure, up and down, similarly assists for the declination. A delicate motion in declination is effected by moving the wooden lever, just over his head, which is attached to one of the declination slow-motion wheels. A three-minute periodicity in the clock-train, with double amplitude six seconds of arc, moves the star back and forth along the slit. This motion would be a convenience if it were a trifle smaller. At present it carries the star out at one end or the other of the slit, but the observer brings it back by a slight pressure on the rod in his right hand.

The spectrum plates are measured by means of a micrometer microscope. It is an exact duplicate of that used at Potsdam, of which an illustration is given in Frost's Scheiner's *Astronomical Spectroscopy*, p. 102. The instrument was kindly secured for us by Professor Vogel. I have measured about 100 plates with it, from 20 to 45 lines on each plate. It is practically perfect for its purpose. The pitch of the micrometer screw is $0^{mm}.25$. The head is divided to 100 parts, and can be read to tenths of a division. I tested the screw for possible errors by comparing it with a ruled glass scale which was standardized for the Lick Observatory by Assistant O. H. Tittmann of the United States Coast and Geodetic Survey.[1] The scale was clamped to the table of the microscope and readings secured on all the lines from 0 to 84 of the glass scale, and from 12 to 184 revolutions of the screw. The irregularities in the scale were shown clearly, but the apparent errors in the screw were of the same order as

[1] See *Publications of the Lick Observatory*, 3, 153–160.

the probable errors of the readings on the lines. The comparisons furnished the following values for one revolution of the screw:

At 27°.1 C.	$r = 0^{mm}.24999$
21 .1	0 .24998
17 .8	0 .24999
15 .0	0 .24999
14 .6	0 .24998
13 .9	0 .24999
12 .8	0 .24998
	Mean $0^{mm}.24999$

A variation of four units of the last place would be expected from the temperature variation, but it is not shown.

As a basis for reducing the photographs I carefully measured the position of 22 selected lines on Plate 433A of the solar spectrum. Their wave-lengths from Rowland's tables are contained in the first column of Table I below. The next column contains the corresponding micrometer readings. In order to determine the relation existing between micrometer readings and wavelengths, I assumed the origin for abscissae to lie at λ4330, near the middle of the plate, and the origin for ordinates at micrometer reading 32,000. Letting x be the distance in tenth-meters of any line from λ4330, I assumed the relation

$$\text{Reading at } (\lambda 4330 + x) = R = 32.000 + A + Bx + Cx^2 + Dx^3. \quad (7)$$

The values of $R - 32.000$ and of x are given in the table. The twenty-two lines furnished as many equations for determining the values of A, B, C, and D. These were solved by the method of least squares, whence I obtained

$$R = 32.000 + 0.0405 + 0.3238298x - 0.000251716x^2 + 0.000000199041x^3. \quad (8)$$

The values of the micrometer readings computed from this formula are given in column 5 of the table, followed by the residuals, observed minus computed. The curve represents the observations very satisfactorily. Intermediate lines are represented equally well.

TABLE I.

λ	Observed R	$R-32.000$	$x=\lambda-4330$	Computed R	Residuals O—C
4238.970	0.325	−31.675	− 91.030	0.326	−0.001
46.996	3.314	−28.686	− 83.004	3.313	+0.001
54.505	6.072	−25.928	− 75.495	6.073	−0.001
67.985	10.934	−21.066	− 62.015	10.943	−0.009
76.836	14.089	−17.911	− 53.164	14.083	+0.006
82.565	16.096	−15.904	− 47.435	16.092	+0.004
89.525	18.512	−13.488	− 40.475	18.508	+0.004
4303.337	23.224	− 8.776	− 26.663	23.224	0.000
13.797	26.722	− 5.278	− 16.203	26.726	−0.004
18.817	28.390	− 3.610	− 11.183	28.387	+0.003
27.274	31.157	− 0.843	− 2.726	31.156	+0.001
31.811	32.627	+ 0.627	+ 1.811	32.626	+0.001
38.084	34.645	+ 2.645	+ 8.084	34.642	+0.003
41.530	35.740	+ 3.740	+ 11.530	35.741	−0.001
59.784	41.459	+ 9.459	+ 29.784	41.467	−0.008
69.941	44.582	+12.582	+ 39.941	44.586	−0.004
79.396	47.449	+15.449	+ 49.396	47.446	+0.003
88.571	50.186	+18.186	+ 58.571	50.184	+0.002
4406.810	55.516	+23.516	+ 76.810	55.519	−0.003
17.884	58.696	+26.696	+ 87.884	58.691	+0.005
30.785	62.326	+30.326	+100.785	62.325	+0.001
4442.510	65.570	+33.570	+112.510	65.572	−0.002

Table II contains a list of 109 lines which I have had occasion to use in determining stellar velocities. Only a small portion of the table is published here, by way of illustration. The wave-lengths are Rowland's, and the corresponding micrometer readings are computed from formula (8) for the standard solar reduction plate, 433A. The quantity, rV_s, is the velocity in kilometers per second corresponding to a displacement of the lines through one revolution, r, of the micrometer screw. The velocity V_s in kilometers per second corresponding to a displacement of one tenth-meter is given by[1]

$$V_s = \frac{299860}{\lambda}. \tag{9}$$

The value of r is readily obtained from (8). Differentiating it we have

$$\frac{dx}{dR} = \frac{1}{B + 2\,Cx + 3\,Dx^2}. \tag{10}$$

[1] See my paper on "The Reduction of Spectroscopic Observations," reprinted in Frost's Scheiner's *Astronomical Spectroscopy*, p. 339.

If we assume that dR is unity, dx becomes the value of one revolution of the micrometer screw in tenth-meters; that is,

$$dx = r = \frac{1}{B + 2Cx + Dx^2}; \qquad (11)$$

the values of B, C, and D being given in (8).

TABLE II.

λ	⊙ Micrometer Reading	rV_s
4238.188	0.033	188.6
38.970	0.326	188.8
..	..	..
..	..	..
..	..	..
..	..	..
4337.216	34.363	215.9
37.414	34.427	216.0
37.725	34.528	216.0
38.084	34.642	216.1
..	..	..
..	..	..
..	..	..
..	..	..
4441.881	65.399	245.5
42.510	65.572	245.6

A table computed for every five tenth-meters is very convenient in making interpolations for lines previously unused, and for many other purposes, but need not be published here. It should contain the corresponding micrometer reading, the value of one revolution in tenth-meters, its reciprocal, which is the value of one tenth-meter in terms of the micrometer revolution, and the value of rV_s.

The correction for the curvature of the spectrum lines was determined empirically from lines in the solar spectrum. Assuming that the curve is a parabola, the deviations x from the tangent at the vertex were measured for several points on the line at distances y from the axis of the parabola. The equation of the parabola was secured by a least squares solution. The equations for three lines, expressed in terms of the micrometer units, are :

$$\begin{aligned} \text{for } \lambda\, 4238.188 \qquad & x = -\,0.00233\,y^2 \\ \lambda\, 4338.084 \qquad & x = -\,0.00224\,y^2 \qquad (12) \\ \lambda\, 4342.510 \qquad & x = -\,0.00208\,y^2 \end{aligned}$$

The equation for the line λ4338.084, computed from the known constants of the instrument, from Ditscheiner's formula[1] is $x = -\,0.00210y^2$. I have preferred to use the empirical formulae.

The corrections for curvature corresponding to various distances y of the comparison spectrum from the center of the star spectrum, are given in kilometers per second in Table III.

TABLE III.

y	λ4238.188	λ4338.084	λ4442.510
$0^r.0$	$-0^{km}.00$	$-0^{km}.00$	$-0^{km}.00$
0 .2	−0 .02	−0 .02	−0 .02
0 .4	−0 .07	−0 .08	−0 .08
0 .6	−0 .15	−0 .17	−0 .18
0 .7	−0 .22	−0 .24	−0 .25
0 .8	−0 .28	−0 .31	−0 .33
0 .9	−0 .36	−0 .39	−0 .41
1 .0	−0 .44	−0 .48	−0 .51
1 .1	−0 .53	−0 .59	−0 .62
1 .2	−0 .63	−0 .70	−0 .74
1 .3	−0 .74	−0 .82	−0 .86
1 .4	−0 .86	−0 .95	−1 .00
1 .5	−0 .99	−1 .09	−1 .15

The corrections for the annual and diurnal motions of the Earth are computed from my tables and formulae[2] for that purpose. I have, however, adopted the new value of the solar parallax, 8″.8, which requires each value of log V_a to be increased by 0.0019. Likewise, the results are referred to the ecliptic and mean equinox of 1900.0.

Heretofore I have kept the violet end of the plate to the left while measuring it on the micrometer microscope. I have not detected any systematic differences between the measures made with violet to the left and violet to the right, such as those found by Professor Lord.[3] Actual trials do not show it. Further, all my measures of planetary velocities, obtained with violet to

[1] See Frost's Scheiner, p. 15.

[2] See Frost's Scheiner, pp. 338–345.

[3] See this JOURNAL, **6**, 424–426.

the left, agree with the computed velocities very satisfactorily, and that is evidently the criterion in such questions. Some of Mr. Wright's measures, but not all, show a systematic difference of that character — one plate shows a change of $1^{km}.5$, or $0^{km}.75$ from the mean, by measurement in the two directions, whereas another shows no change whatever. Mr. Wright has, I believe, measured in both directions from the first. As the time formerly spent in triplicate measures in one direction may be divided between measures in two directions, I shall probably adopt that method for the sake of uniformity in our system.

In order to illustrate the methods employed, I shall insert my reduction of Plate 252 B, α Tauri, taken 1897 January 20, Mt. Hamilton sidereal time $3^h\ 51^m$. Column 1 contains the Rowland wave-lengths of the lines, both stellar and comparison, that were measured on this plate. The next column contains the micrometer readings for the same lines on the standard solar reduction plate, taken from Table II. It should be said that the standard solar plate was secured with the triple camera lens now in use, whereas this plate of α Tauri was made with the discarded double camera lens. The reduction curves for the two lenses are slightly different, but their second differences are practically identical, so that either curve will answer all requirements. Column 3 contains the micrometer readings on the star lines, each the mean of three settings, and column 4 contains the readings on the comparison lines of iron and hydrogen. The next column, "zero lines," contains the micrometer readings that comparison lines, or *lines of zero velocity*, would have if there were such lines having the wave-lengths given in column 1. They are the readings of the corresponding solar lines reduced to the curve on which the Fe and H comparison lines lie. These values are readily and accurately supplied. The micrometer readings on the comparison lines are assumed to be correct. A curve similar to the *corresponding section* of the solar curve is analytically passed through each adjacent pair of comparison lines, and the readings on this curve corresponding to the wave-lengths of the lines observed in the star spectrum are obtained

by interpolation. Sections of the solar curve are passed through the comparison lines, pair by pair, throughout the spectrum. [The iron lines $\lambda\lambda 4294.3$ and 4299.4 are usually treated as one line in their mean position $\lambda 4296.9$]. The micrometer readings supplied for the zero lines are as accurate as those for the comparison lines obtained by measurement. It would be a simple matter to plot the readings on all the comparison lines, pass a smooth curve through them as well as possible, and read off the ordinates for the zero lines. There is little to gain or lose by a choice between the two methods, and I have preferred the former.

The micrometer readings on the star lines, minus those on the comparison and zero lines, are the observed displacements. The value of rV_s varies for different plates, owing to changes of temperature, etc. The comparison lines on each plate furnish the reduction constants for that plate, and the relative linear scales of the stellar and standard solar plates permit the modified values of rV_s to be readily filled in from Table II. The measured velocities v_s are quickly found by means of Crelle's tables. The mean of the velocities from the twenty-eight star lines is $+79^{\mathrm{km}}.17$. The readings on the comparison lines were made at a distance $0^{\mathrm{r}}.85$ from the center of the star spectrum. Hence the correction for curvature is $-0^{\mathrm{km}}.35$. The reduction to the Sun[1] is $v_a + v_d = -23^{\mathrm{km}}.90$. Therefore the velocity with reference to the solar system is $V = +54^{\mathrm{km}}.9$.

It will be noticed that I made little use of the iron lines in the star spectrum corresponding to the iron comparison lines. There are relatively few second-type stars in which those iron lines are suitable for measurement, owing to their breadth or to the influence of close companions. The best lines are selected irrespective of their positions, and the positions of their zero lines of reference are computed later. Thus one never knows what displacements these lines may have until column 6 on the reduction sheet is filled in.

[1] In theory, the reductions should be made with reference to the ecliptic and equinox of the observation date, but no sensible error is introduced by reducing uniformly to 1900.0.

α TAURI.— PLATE 252 B.

λ	⊙	*	Fe and H	Zero lines	Displacement	rV_s	V_s
4282.565	16.092		15.859				
87.566	17.831	17.987		17.591	$+0^r.396$	202.7	$+80^{km}.3$
94.301	20.150		19.897	19.899			
99.410	21.893		21.637	19.635			
4300.211	22.165	22.287		21.907	.380	206.1	78 .3
00.732	22.342	22.469		22.084	.385	206.3	79 .4
02.692	23.006	23.136		22.746	.390	206.9	80 .7
08.081	24.819		24.553				82 .1
15.262	27.213		26.942				
16.962	27.775	27.892		27.502	.390	210.5	
25.939	30.721		30.441				
26.520	30.911	31.016		30.631	.385	213.3	82 .1
27.274	31.156	31.225		30.876	.349	213.5	74 .5
28.080	31.418	31.501		31.137	.364	213.7	77 .8
33.925	33.308	33.394		33.026	.368	215.3	79 .2
37.216	34.363	34.443	34.080		.363	216.3	78 .5
37.725	34.528	34.603		34.244	.359	216.4	77 .7
38.084	34.642	34.708		34.358	.350	216.5	75 .8
38.430	34.753	34.840		34.469	.371	216.6	80 .3
38.854	34.888	34.973		34.603	.370	216.7	80 .2
40.634	35.456	35.535	35.169		.366	217.1	79 .5
41.167	35.626	35.711		35.339	.362	217.1	78 .6
41.530	35.741	35.811		35.454	.357	217.2	77 .6
43.861	36.481	36.564		36.194	.370	217.9	80 .6
44.670	36.738	36.811		36.451	.360	218.1	78 .5
47.403	37.601	37.678		37.313	.365	218.9	79 .9
49.107	38.137	38.212		37.849	.363	219.4	79 .7
55.257	40.062	40.141		39.773	.368	221.1	81 .4
59.784	41.467	41.543		41.178	.365	222.4	81 .2
69.941	44.586	44.645		44.295	.350	225.3	78 .9
76.107	46.456	46.515		46.165	.350	227.1	79 .5
79.396	47.446	47.495		47.155	.340	228.0	77 .5
83.720	48.741		48.449				
89.413	50.433	50.487		50.141	.346	230.9	79 .9
4404.927	54.975		54.683				
06.810	55.519	55.554		55.227	+0.327	235.8	+77 .1

Mt. Ham. Sid. T. 1897 Jan. 20	$3^h\ 51^m$	Mean	$= +79\ .17$
α 1900.0 =	4 30	Corr. for Curvature	$= -\ 0\ .35$
$\tau = -$	0 39	Reduction to ⊙	$= -23\ .90$
δ 1900.0 =	$+16^\circ\ 18'$	V	$= +54^{km}.92$
Greenwich M. T. 1897 Jan. 20	$15^h\ 55^m$		

β 1900.0	$= -\ 5^\circ\ 28'.5$	$\log v_a$	$= 1.4805$
λ 1900.0	$= 68\ 23\ .5$	$\sin(\lambda - \odot + i)$	$= 9.9009$
⊙ 1900.0	$= 301\ 28\ .6$	$\cos\beta$	$= 9.9980$
i	$= +\ 20\ .0$	$\log v_a$	$= 1.3794n$
$\lambda - \odot + i$	$= 127\ 14\ .9$	v_a	$= -\ 23^{km}.96$
		v_d	$= +\ 0\ .06$

Several hundred plates of star spectra have been obtained, and about 150 have been measured and reduced. In order to show the nature of the results, I append a list of fifty velocity determinations for eleven stars, the only stars for which I have reduced four or more plates each. The results obtained by other observers are printed for comparison in the adjoining columns. Those by Professors Vogel and Scheiner found in the same horizontal line are the results obtained by the two observers from one and the same plate. The results are all expressed in kilometers per second.

DETERMINATIONS.

Star	Mt. Hamilton Sid. time	Campbell	Vogel	Scheiner	Other observers
α Cassiopeiae	1896 Nov. 12, 0^h 54^m	— 4.1	—14.8	—17.0	Lord, photo. — 2.8
	Dec. 8, 1 00	— 4.1	—15.0	—14.1	" " + 1.6
	" 17, 1 42	— 4.9			
	" 24, 1 45	— 4.2			
	Means	— 4.3	—14.9	—15.6	— 0.6
β Andromedae	1896 Dec. 8, 2 58	+ 0.8	+ 3.9	+11.7	
	" 17, 2 36	— 0.8	+14.0	+14.9	
	" 24, 2 40	— 1.0			
	1897 July 8, 22 56	+ 0.6			
	" 21, 22 27	+ 2.1			
	Means	+ 0.3	+ 9.0	+13.3	
α Ursae Minoris	1896 Sept. 8, 2 00	—20.1	—21.1	—25.9	
	" 15, 2 23	—19.1	—29.9	—26.5	
	" 23, 1 34	—18.9			
	Oct. 5, 1 52	—19.0			
	Nov. 11, 2 40	—20.1			
	Dec. 8, 1 50	—20.3			
	Means	—19.6	—25.5	—26.2	
γ Andromedae	1896 Nov. 12, 2 32	—12.0	— 5.6	—16.1	
	1897 Jan. 5, 2 35	—12.8		—21.6	
	July 22, 23 36	—10.8	—10.3	—15.7	
†	1898 July 12, 22 45	—10.6			
*	" 12, 22 45	— 9.5			
†	" 13, 23 09	—11.2			
	Means	—11.2	— 8.0	—17.8	

* Independent measures and reductions by Mr. Wright.

† Photographs taken by Mr. Wright.

DETERMINATIONS —*continued.*

Star	Mt. Hamilton Sid. time	Campbell	Vogel	Scheiner	Other observers	
α Arietis	1896 Aug. 19, 0 30	−13.8	−12.8	−21.0	Lord, photo.	−12.6
	" 25, 1 11	−14.0	−13.2	−10.5	" "	−15.3
	Dec. 9, 0 36	−14.2	−17.4	−13.2		
	" 9, 1 07	−14.4				
	Means	−14.1	−14.5	−14.9		−14.0
α Persei	1896 Nov. 11, 3 35	− 2.0	−10.8	− 9.5		
	" 12, 3 24	− 1.8	−10.8	−10.1		
	1897 Jan. 19, 3 57	− 3.5				
†	1898 July 12, 23 40	− 2.1				
	Means	− 2.4	−10.8	− 9.8		
α Tauri	1896 Aug. 23, 3 04	+55.7	+44.4	+49.0	Keeler, visual	+57.3
	Sept. 16, 3 15	+54.6	+49.0	+49.0	" "	+60.1
	Dec. 8, 4 03	+54.5	+46.3	+46.7	" "	+48.3
	" 17, 3 19	+54.3	+50.6	+52.8	Campb'll, visual	+49.1
	1897 Jan. 20, 3 51	+54.9			Newall, photo.	+49.2
‡	1898 Jan. 19, 4 55	+55.2				
	Means	+54.8	+47.6	+49.4	Keeler	+55.2
α Canis Minoris	1897 Jan. 20, 6 33	− 5.0	− 8.5	−13.7	Newall, photo.	− 4.9
	" 21, 6 38	− 4.3	− 9.3	−13.4		
	Feb. 21, 8 01	− 4.8	− 5.9	− 4.4		
	" 22, 7 42	− 5.0				
	Means	− 4.8	− 7.9	−10.5		− 4.9
α Ursae Majoris	1897 Jan 21, 11 20	−10.3	− 8.1	−15.3		
	Feb. 24, 12 10	− 9.5	− 9.9	−14.7		
	April 15, 11 42	−10.0	−10.6	− 8.8		
†	Dec. 23, 11 33	− 9.5	−12.5	−11.9		
*	" 23, 11 33	− 9.5				
	Means	− 9.8	−10.3	−12.7		
γ Draconis	1897 May 4, 19 00	−27.4				
	" 27, 19 09	−28.4				
	July 20, 18 58	−26.3				
	Aug. 3, 19 05	−27.4				
	Mean	−27.4				
ε Pegasi	1896 Aug. 27, 21 06	+ 5.5	+ 5.5	+ 2.6	Lord, photo.	+ 6.8
	1897 July 8, 21 03	+ 5.7	+ 9.1	+14.7	" "	+ 8.3
†	1898 June 15, 21 10	+ 6.4			" "	+14.7
†	" 26, 21 25	+ 5.2				
	Means	+ 5.7	+ 7.3	+ 8.6		+ 9.9

‡ Photograph, measures and reductions by Mr. Wright.

The extreme accuracy required and attained in this class of work is evident from the following statement. The linear value of 0.01 second of arc in the focus of the 36-inch refractor is $0^{mm}.000857$. On the spectrum plates, $0^{mm}.000857$ is 0.0034 revolution of the screw, corresponding to $0^{km}.74$ per second displacement. It is not surprising, therefore, that great care and considerable experience are absolutely necessary for suitable measurement of the plates. The lines to be measured require good judgment in their selection. Some of the best lines in the solar spectrum are practically useless in many stars, owing to the changed intensities of close companion lines. To mention only one case, the line at $\lambda 4318.817$ is excellent in the solar spectrum, but a close companion seriously affects it in nearly all the second type stars thus far measured.

The necessity for guarding against systematic errors has been constantly held in mind. No difficulties of that sort have yet been encountered. The velocities of Mars and Venus have been observed on several occasions, with the telescope on both sides of the pier, and at both large and small hour angles. The accompanying tables will show the agreement between observed and computed velocities.

It is desirable to have a simple formula for computing the velocity of a planet at any instant with reference to the Earth, and with reference to the Sun.

Let D be the distance between the two bodies whose relative velocity is required. The American Ephemeris tabulates the function

$$f = \log D$$

at regular intervals and stated times, for each planet and the Earth, and for each planet and the Sun. Let T be the date in the ephemeris nearest the instant for which the velocity is required, and let ω be the tabular interval of time. Then the adjacent dates in the ephemeris may be represented as in column 1 of the table below, and the corresponding values of the function $f = \log D$ as in column 2. The remaining columns

$T-2\omega$	$f(T-2\omega)$				
		$a_{\prime\prime}$			
$T-\omega$	$f(T-\omega)$		b'		
		$a_{\prime}$		$c_{\prime}$	
T	$f(T)$	a	b	c	d
		a'		c'	
$T+\omega$	$f(T+\omega)$		$b_{\prime}$		
		a''			
$T+2\omega$	$f(T+2\omega)$				

contain the first, second, third, and fourth "differences" of the function f, formed in the usual manner. Lastly, the quantities $a = \frac{1}{2}(a_{\prime} + a')$ and $c = \frac{1}{2}(c_{\prime} + c')$ are inserted in the positions indicated.

Let the instant for which the velocity is wanted be represented by $T+t$; and let n be the ratio of t and the tabular interval ω; *i. e.*, $n = t/\omega$, or $t = n\,\omega$. The formula for computing $\log D$ at the time $T+t$ from the above data is[1]

$$\log D = f(T+t) = f(T)$$
$$+\left(a-\frac{c}{6}\right)n+\left(\frac{b}{2}-\frac{d}{24}\right)n^2+\frac{c}{6}n^3+\frac{d}{24}n^4+\;.\;.\;. \qquad (13)$$

The rate of change of $\log D$ at that instant is

$$\frac{\delta}{\delta t}\log D = \frac{\delta}{\delta t}f(T+t);$$

whence, letting m be the modulus of the logarithmic system used,

$$\frac{\delta D}{\delta t} = \frac{D}{m}\left[a-\frac{c}{6}+\left(b-\frac{d}{12}\right)n+\frac{c}{2}n^2+\frac{d}{6}n^3+\;.\;.\;.\right]. \qquad (14)$$

Now $\frac{\delta D}{\delta t}$ is the desired velocity at the time $T+t$, but expressed in terms of the astronomical unit of distance employed in the ephemeris, and of the tabular unit of time ω. The astronomical unit of distance corresponding to the solar parallax 8″.80 is 149,500,000 kilometers. If ω is expressed in

[1] An adaptation of formula (71), Vol. I, Chauvenet's *Spher. and Prac. Astronomy*, 5th edition.

MARS.

Mt. Hamilton M. T.	No. of lines measured	Measured velocity v_s	Corr. for curv.	Observed velocity	Relative velocity ♂ − ⊕	Relative velocity ♂ − ⊙	Diurnal velocity, $-v_d$	Computed velocity	Residuals O − C
1896, Sept. 15d 16h 13m	33	− 8.66	−0.39	− 9.05	−10.38	+1.94	−0.11	− 8.55	−0.50
Oct. 3 16 43	30	− 7.86	−0.39	− 8.25	−10.35	+2.12	+0.01	− 8.22	−0.03
1897, Jan. 14 08 05	18	+14.79	−0.39	+14.40	+12.71	+1.90	−0.08	+14.53	−0.13

VENUS.

Mt. Hamilton M. T.	No. of lines measured	Measured velocity v_s	Corr. for curv.	Observed velocity	Relative velocity ♀ − ⊕	Relative velocity ♀ − ⊙	Diurnal velocity, $-v_d$	Computed velocity	Residuals O − C
1897, July 22d 16h 09m	37	+13.92	−0.82	+13.10	+13.56	−0.17	−0.33	+13.06	+0.04
* July 22 16 09	32	+14.80	−0.81	+13.99				+13.06	+0.93
† Aug. 26 16 52	31	+12.14	−0.62	+11.52	+12.06	−0.24	−0.31	+11.51	+0.01
‡ Aug. 26 16 52	27	+12.36	−0.70	+11.66				+11.51	+0.15
1898, June 8 07 58	31	− 9.04	−0.62	− 9.66	− 9.56	+0.08	+0.34	− 9.14	−0.52
* June 8 07 58	22	− 8.71	−0.90	− 9.61				− 9.14	−0.47

* Independent measures and reductions of the same plate by Mr. Wright.

† Photograph, measures, and reductions by Mr. Wright.

‡ Independent measures and reductions of the same plate by Mr. F. C. Cottrell.

seconds of mean solar time, the desired velocity V will be given in kilometers per second by

$$\frac{\delta D}{\delta t} = V =$$

$$\frac{149{,}500{,}000}{\omega m} D\left[a - \frac{c}{6} + \left(b - \frac{d}{12}\right)n + \frac{c}{2}n^2 + \frac{d}{6}n^3 + \ldots\right]; \quad (15)$$

or, for logarithmic computation,

$$\log V = \log \frac{149{,}500{,}000}{\omega m} + \log D + \log [\,.\,.\,.\,.\,].^* \quad (16)$$

The following table contains the values of $\log \frac{149{,}500{,}000}{\omega m}$ in the cases which may arise.

If $\omega = 1$	mean solar day,	$\log \frac{149{,}500{,}000}{\omega m}$	$= 3.6003$
" $\omega = 2$	" " days,	"	$= 3.2993$
" $\omega = 4$	" " "	"	$= 2.9983$
" $\omega = 8$	" " "	"	$= 2.6973$

Example. Required the velocity of Venus with reference to the Earth at Mt. Hamilton mean time, 1898, June 8^d 7^h 58^m.

The Greenwich mean time is June 8^d 16^h 05^m. The American Ephemeris gives for

Greenwich M. T.	log D	a	b	c	d
1898, June 5.0......	0.1591081				
		—32651			
" 7.0......	0.1558430		—818		
		—33469		—12	
" 9.0......	0.1524961	—33884	—830	—14	—3
		—34299		—15	
" 11.0......	0.1490662		—845		
		—35144			
" 13.0......	0.1455518				

In this case the assigned instant precedes $T =$ June 9.0 by 7^h 55^m, and $\omega = 2$ days. Therefore

$$n = -\frac{7^h\ 55^m}{2 \text{ days}} = -0.165.$$

* The form [. . . .] is used to express the quantity within the brackets in (15).

Solving (13) and (16) we have

$$\begin{aligned} f(T) &= +\ 0.1525 \\ \left(a - \frac{c}{6}\right) n &= +\qquad 6 \\ \hline \log D &= +\ 0.1531 \end{aligned} \qquad\qquad \begin{aligned} a - \frac{c}{6} &= -\ 0.003388 \\ \left(b - \frac{d}{12}\right) n &= +\qquad 14 \\ \hline [\ .\ .\ .\ .\ .\ ] &= -\ 0.003374 \end{aligned}$$

$$\begin{aligned} \log \frac{149{,}500{,}000}{\omega\, m} &= 3.2993 \\ \log D &= 0.1531 \\ \log [\ .\ .\ .\ .\ ] &= 7.5281_n \\ \hline \log V &= 0.9805_n \\ V &= -\ 9^{\mathrm{km}}.56 \end{aligned}$$

Example. Required the velocity of Venus with reference to the Sun at Mt. Hamilton mean time, 1898, June $8^{\mathrm{d}}\ 7^{\mathrm{h}}\ 58^{\mathrm{m}}$.

As in the preceding example, the Greenwich mean time is 1898, June, $8^{\mathrm{d}}\ 16^{\mathrm{h}}\ 05^{\mathrm{m}}$, and we have from the Ephemeris for

Greenwich M. T.	log R	a	b	c	d
1898, June 1.0........	9.8563710				
		+ 568			
" 5.0........	9.8564278		+371		
		+ 939		−14	
" 9.0........	9.8565217	+1118	+357	−16	−4
		+1296		−18	
" 13.0........	9.8566513		+339		
		+1635			
" 17.0........	9.8568148				

In this case $T =$ June 9.0 and $n = -0.082$.

The solutions of (13) and (16) are

$$\begin{aligned} f(T) &= 9.8565 \\ \left(a - \frac{c}{6}\right) n &= \qquad 0 \\ \hline \log R &= 9.8565 \end{aligned} \qquad\qquad \begin{aligned} a - \frac{c}{6} &= +\ 0.000112 \\ \left(b - \frac{d}{12}\right) n &= -\qquad 3 \\ \hline [\ .\ .\ .\ .\ .\ ] &= +\ 0.000109 \end{aligned}$$

$$\log \frac{149{,}500{,}000}{\omega\, m} = 2.9983$$
$$\log R = 9.8565$$
$$\log [\,.\;.\;.\;.\;.\,] = 6.0374$$
$$\log V = 8.8922$$
$$V = +0^{\mathrm{km}}.08$$

I have endeavored throughout to employ only those methods of reduction which will readily enable revisions to be made in case it is desired to use slightly different values of the wave-lengths: whether due to changes in the tables of standard wave-lengths, or to effects of pressure, or to any other causes.

The results contained in this paper were practically ready for publication one year ago, but the publication was delayed by my preparations for observing the total solar eclipse in India, and by an absence of seven and a half months from the Observatory. The work has been carried on during my absence by Mr. W. H. Wright, Assistant Astronomer.

LICK OBSERVATORY,
UNIVERSITY OF CALIFORNIA.
July 20, 1898.

SOME STARS WITH GREAT VELOCITIES IN THE LINE OF SIGHT.

By W. W. Campbell.

In the course of our work on the spectrographic determinations of stellar motions, I have detected a number of cases of great velocities in the line of sight.

Mr. Wright and I have secured four plates of the spectrum of η Cephei, which furnish the following velocities with reference to the solar system:

Date			No. of lines measured	Velocity
1897	September	29	34	$-87^{km}.6$
	"	*	18	$-87\ .2$
1898	July	20	39	$-86\ .2$
	August	21	34	$-86\ .9$
	August	25	31	$-86\ .2$
			Mean	$-86^{km}.8$

The proper motion of η Cephei is about 0″.8.

We have confirmed M. Belopolsky's results for the brighter component of ζ Herculis [*A. N.*, **133**, 257–262]. Our results from four plates, together with M. Belopolsky's results from seven plates, are as follows:

Date			No. of lines measured	Velocity	Belopolsky
1897	April	29	22	$-69^{km}.1$	-68^{km}
1898	May	11	42	$-70\ .4$	-84
	May	23	36	$-70\ .0$	-75
	May	*	32	$-71\ .1$	-67
	August	19	34	$-70\ .9$	-66
					-64
					-69
			Means	$-70^{km}.3$	-70^{km}

* Independent measures and reductions of the same plate by Mr. Wright.

We may refer, in this connection, to the large velocity obtained by Professor Keeler for the planetary nebula *G. C.* 4373. His result from measures on six nights is $-64^{km}.7$ per second.

It should be noted that the results for all the above objects will be numerically decreased when we apply the correction for solar motion. Thus, if we assume that the solar system is moving toward the point $\alpha = 267^\circ$, $\delta = +31^\circ$, with a velocity of 17^{km} per second, the corrections for the solar motion are as given in column two below, and the velocities with reference to the sidereal system become as in column three.

Object	Correction	Velocity
η Cephei	+12.7	$-74^{km}.1$
ζ Herculis	+16.4	$-53\ .9$
G.C. 4373	+13.8	$-50\ .9$

LICK OBSERVATORY,
August 29, 1898.

THE VARIABLE VELOCITY OF η PEGASI IN THE LINE OF SIGHT.

By W. W. CAMPBELL.

MY first measures of the velocity of η Pegasi from three spectrum plates gave $+7.1$, $+5.1$, and -2.2 kilometers, respectively. Inasmuch as an extreme range of four kilometers is never expected and would lead to a careful reëxamination of the plates and of the results obtained for other stars on the same night, I felt sure that the velocity of η Pegasi varied. Additional plates were secured and measured and another earlier plate was reduced. All confirm the variation. The velocities obtained up to date are as follows:

1896	Aug. 27	$+7^{km}.1$
	Sept. 23	$+5\ .1$
1897	July 8	$-6\ .4$
	Sept. 28	$-2\ .2$
1898	Aug. 29	$+16\ .5$
	Aug. 30	$+15\ .6$
	Sept. 4	$+16\ .5$

The extreme range observed is 23^{km}. It is pretty certain that the period is a long one, possibly in the neighborhood of two years. Since it may be several years before the character of the motion can be investigated, it seems proper to announce the fact of the variation at once. If other observers have secured observations of this star, I should be glad to receive their results to assist in determining the period.

LICK OBSERVATORY,
September 5, 1898.

A SPECIMEN CHART FROM THE ATLAS STELLARUM VARIABILIUM.

By J. G. Hagen, S. J.

The following lines are written in response to the kind invitation of one of the editors, as an explanatory text to the specimen chart from the forthcoming *Atlas of Variable Stars.*

1. It will not be without interest to know the general plan of the atlas; because the plan of a work is its most essential part, it might be called its soul; and if this atlas ever succeeds in being useful to astronomy, it will be owing to its well defined and limited plan. This remark is called forth by an inspection of the late Pogson's manuscripts, which I had the privilege of making lately at the Harvard College Observatory. While a fuller report on these manuscripts is reserved for another occasion, it may be well to state here in a general way that Pogson had been preparing charts for all the known variable stars, including the southern sky, with all the surrounding stars down to the 13th magnitude within 80′ square. Unfortunately his labors of more than a quarter century have not become available to his fellow astronomers because his work had the germ of death in its very plan. It was too extended for him to finish, and put in a shape that makes it inconvenient for practical use.

It will be seen from the accompanying chart, that the field containing the faintest comparison stars has been confined to 30′ square, or less than one seventh of Pogson's area.

Excluded from the atlas are, for the present, all those variable stars, whose range of variability is not yet established with certainty, also the so-called Novae, and finally the variable star clusters. The Novae are not variable stars in the ordinary sense of the word, and ought not to be embodied in the catalogues of variable stars, lest novices in this branch of astronomy be misled to waste time on these historical objects.

As regards the few star clusters that are known to contain

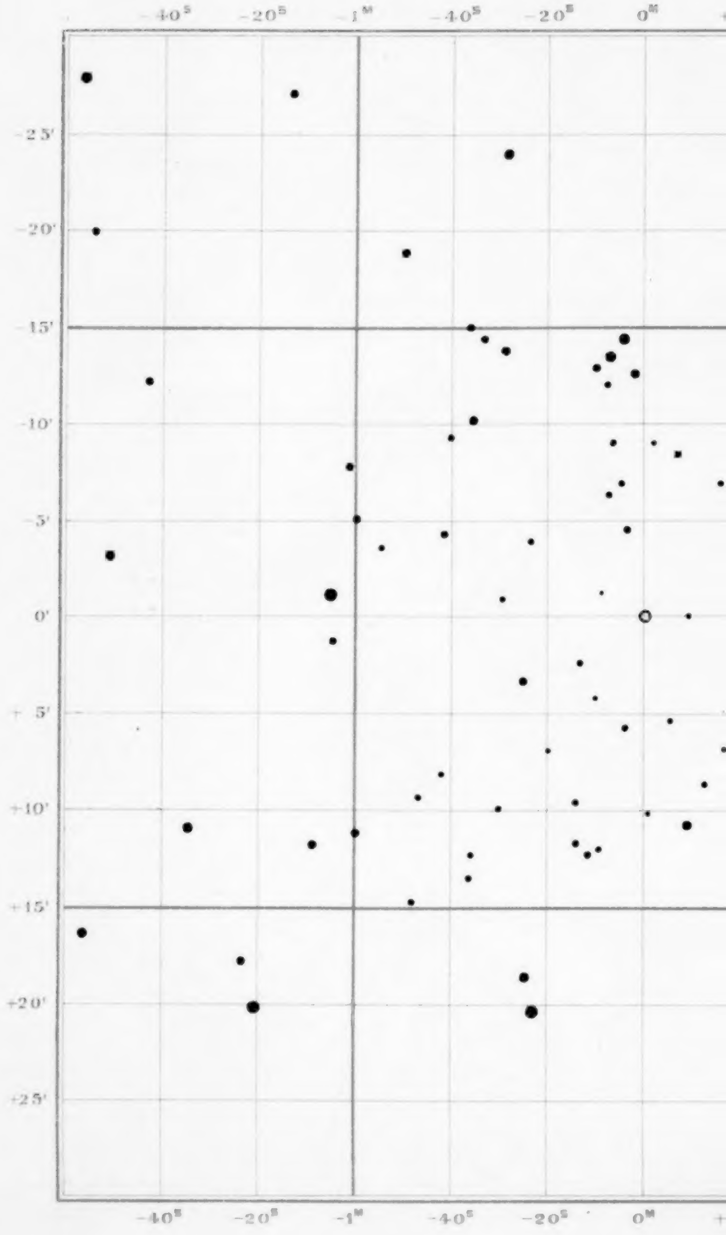
PLATE V.

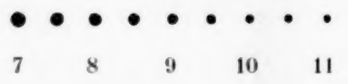
2857

U Pup

(1900.0) $7^h\ 56^m\ 8^s$ $(+2.^s81)$

Color: 3.2; III. Magn





Series I.

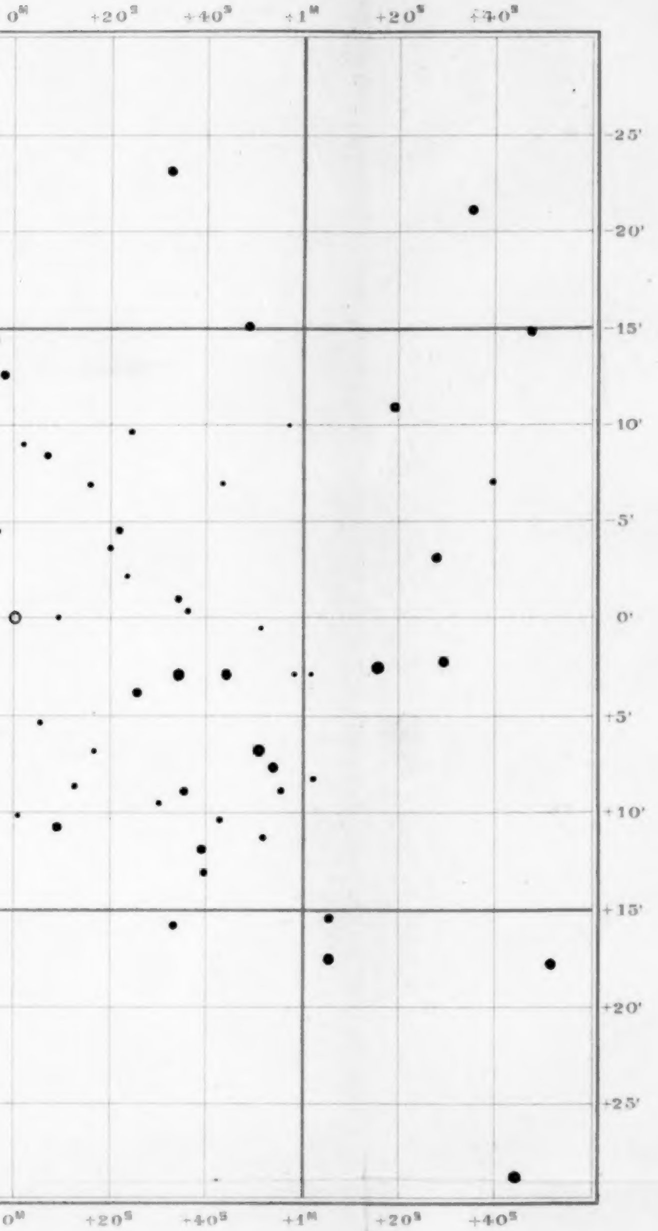
ATE V.

857

uppis

81) — 12° 33.′8 (– 0.′16)

Magnitudo: 8½ – < 14.



11 12 13

ies I.

variable stars, observers will obtain at their request photographic prints from the Harvard College Observatory, as was announced by the Director at the astronomical congress held there this summer.

The first three series of this atlas, of which the accompanying chart is a specimen, will contain charts for all variable stars (not excluded by the above rule), within 0° and 115° polar distance, whose minimum brightness is beyond the reach of a three-inch telescope.

The fourth and fifth series will be devoted to those variable stars whose entire range of variation can be followed respectively by a three-inch telescope and by the naked eye.

Observers of variable stars will thus be able to procure for themselves that one of the five series which best suits their instrumental means and their geographical latitude. They will find the programme of their work prepared, the comparison stars mapped, and, what is the greatest advantage of the atlas, the variable star in the center of each chart identified beyond doubt.

2. The methods by which the stars on the charts were determined both as to position and magnitude, would require more space than is intended for this explanatory note. We can refer the reader who wishes to inform himself on this point, to the first announcement of the Atlas in the *Vierteljahrschrift* (XXXI, p. 278), or to a fuller description of the observations and reductions in the *Publications of the A. S. P.* (X, p. 100).

3. An inspection of the accompanying chart shows that it is divided into two parts, one interior and the other exterior, separated from each other by heavy lines. The interior square represents the chart proper, with the variable in the center and all the stars around it that can be easily seen and measured with our twelve-inch equatorial, while the outer part, surrounding this chart and forming itself a square of 1° in both coördinates, contains only the *BD* stars, corrected and supplemented where it was necessary. The circle in the middle of the chart indicates, by its diameter, the maximum light of the variable star. The minimum light, whenever visible in our twelve-inch refractor, is denoted by a smaller disk in the center of this circle. The

identification of the variable star, which is the essential purpose of these charts, seems to be put beyond doubt, because no chart was sent to the engraver before the star in the center was seen to vary by myself, and all the proof sheets have been examined by two observers of high authority, Dr. Hartwig and Mr. H. Parkhurst.

The projection of the charts is, for the first four series, based on Mercator's principle, except that on each chart the lines representing the parallels are placed at equal distances. In this way the engraving, which is done directly from the catalogue by means of a micrometer screw, is greatly facilitated, whilst the distortion of the small field is almost insensible. The red color of the net will completely disappear to the eye when a red lantern is used during the observation. The chart will then resemble the sky as nearly as possible.

The inscription of the chart furnishes what is useful at the telescope, and no more. The "color" is the "redness" of the variable, on Chandler's scale of ten units from white to red, and the Roman figure denotes the spectrum of Secchi's types.

The readers of this JOURNAL may remember, from a previous communication (Vol. VI, pp. 441-443, of this JOURNAL), that the atlas will be accompanied with a catalogue, which gives the positions of all the stars, differentially from the variable, to full seconds of time and to tenths of minutes of arc, and besides the estimates of brightness in steps and the computed magnitudes. The meaning of these magnitudes has been defined in the paper just referred to.

It may be of interest to know that the engraving of the first series, which comprises the variables between 0° and -25° declination, is finished, and that the whole atlas is published by Mr. Felix L. Dames, Berlin W. 62, Landgrafenstrasse 12.[1]

Finally I may be allowed to repeat in this place what has been stated elsewhere, that astronomers are indebted to Miss Catherine W. Bruce for aiding the expensive publication of this atlas.

GEORGETOWN COLLEGE OBSERVATORY,
September 8, 1898.

[1] We are informed that the subscription price for all the five series is 1 mark per chart, and that of a single series 1.20 marks per chart, including the catalogue.

THE VARIABLE STAR U PEGASI.[1]

By G. W. MYERS.

THE excuse for my infringement on your time and patience lies in the fact that Professor Pickering saw fit to put me here, and some of us have come to think that when he makes up his mind on any subject relating to variable star astronomy, the best thing we can do is to concur in his judgment. In this instance, however, I shall allow my opinion that your time and thought might be more profitably employed in practical matters than in listening to me, to assert itself to the extent of enforcing brevity on my part, perhaps even at the expense of clearness To conform to this purpose I shall be able to give but a very meager outline of my recent study of U Pegasi's light changes. The discussion will be published in detail as a *Bulletin* of our Observatory, and copies of it may be had by applying to the library of the University of Illinois.

Professor Pickering has shown, in *H. C. O. Circular* No. 23, that U Pegasi is to be considered a member of the β Lyrae class of variables. In that circular he gives the observations, in the form of a light curve, on which he bases his conclusion, and in the ASTROPHYSICAL JOURNAL for March of this year he shows from the internal evidence of the observations that the reality of the difference of 0 15 of a stellar magnitude in the brightness at the minima cannot be denied. The writer wishes to add, moreover, that a recent observational study of β Lyrae's light change with one of Professor Pickering's polarizing photometers removes from his mind the last vestige of doubt as to whether the attainable accuracy of photometric measures with this instrument is sufficiently high to detect and confirm so small a difference of brightness as this. He is convinced that, with a little experience and care, the probable

[1] Read at the Harvard Observatory Astronomical Conference, August 19, 1898.

error of a single observation in a set of ten could hardly exceed one-fifth of this difference.

For example, with photometer *V*, I triangulated the three stars β, ν, and 8 Lyrae on August 5 inst., with the following results, which I think may be regarded as fairly typical of the character of the work of a beginner with this instrument:

$$\nu-\beta=1.96 \quad 8-\beta=2.48 \text{ and } 8-\nu=0.46.$$

From the last two we have

$$\nu-\beta=2.02,$$

giving a discrepancy of 0.06 of a magnitude. The result of each of six other evenings' work are also well represented by this. I wish, moreover, to emphasize that this is the work of a *beginner.*

Granting the reality of this difference in the minima, the light curve appears to be susceptible of treatment by essentially the same method as that adapted and used by the writer in his recent discussion of β Lyrae's light curve entitled: *Untersuchungen ueber den Lichtwechsel des Sternes β Lyrae,* Muenchen, 1896.

Assuming provisionally, that both bodies are spheres, a lower limit for the eclipse-duration at Min. I can be easily obtained from the observational curve given in *Circular* 23. A little reflection will make it clear that the shorter the eclipse-duration be taken, the larger will be the corresponding distance between centers of the components. If, then, we assume that the eclipse has not begun until the light curve has fallen quite appreciably and that it has ended shortly before the curve ceases to rise, we shall obtain a value for the duration of the eclipse, at all events short enough—perhaps too short—and the corresponding value of the distance of centers must be at all events great enough—perhaps too great. Proceeding thus, I obtain $3^h.3$ for the interval shorter than which the eclipse-duration at Min. I cannot be. The corresponding value of the distance between centers may then be regarded as fixing a superior limit for this orbital element.

ECCENTRICITY.

The fundamental hypothesis underlying the whole discussion is that the light curve of U Pegasi is capable of being explained on the satellite theory.

The uncertainty in the instants of maximum brightness as indicated by the light curve obviously precludes the possibility of deriving an approximate value of the orbital eccentricity of the component from the chief epochs of light variation, as was done with β Lyrae. One may readily convince himself by considerations adduced below, however, that this eccentricity must be quite small.

Taking account of the relative positions of the components at the beginning and end of the eclipse at Min. I, the most elementary considerations give for the distance of centers, r, the expression:

$$r \leqq (x + \kappa) \csc 66^\circ$$
$$\leqq 1.0946\,(x + \kappa)$$

Where x and κ denote magnitudes of such nature that $x \leqq 1$ and $\kappa \leqq 1$. We shall have then $r \leqq 2.189$ times the radius of the larger companion. So small a distance of centers relative to the dimensions of the primary would be physically impossible unless the radius of the secondary were quite inconsiderable compared with that of the primary, which is shown later not to be the case.

It was therefore assumed as a first approximation that $e=0$, and we then proceed to determine the value of the ratio of the brightness of the companions, and to fix the limits within which the ratio of the radii must be comprised. We then undertake to find the most probable value of this latter ratio by direct reference to the light curve of the star.

CIRCULAR ORBITAL ELEMENTS AND LIGHT RATIO OF THE COMPONENTS OF U PEGASI.

The chief epochs of the light curve shall be designated in order of time as Min. I, Max. I, Min. II and Max. II. From

the curve Max. I is seen to have a brightness of 9.32 magnitude and Max. II of 9.34 magnitude, so that the mean value $9^{m}.33$ has been used throughout the discussion for the brightness at both the maxima. For the brightness at Min. I, the value 9.90 magnitude has been used, and for Min. II, 9.75 magnitude. Reducing these differences in stellar magnitudes at the chief epochs of variability to their equivalent light ratios, by the aid of Pogson's scale, we obtain:

$$\frac{\text{Brightness at Min. II}}{\text{Brightness at Min. I}} = c = 1.1480$$

$$\frac{\text{Brightness at Mean Max.}}{\text{Brightness at Min. I}} = m = 1.6904$$

A STUDY OF THE LIGHT CURVE.

Calling the light ratio of the components λ and the portion of the disks common to both bodies at the middle of the eclipses a, the preceding equations give the following:

$$\frac{1 + \kappa^2 \lambda - a \kappa^2 \lambda}{1 - a \kappa^2 + \kappa^2 \lambda} = c \qquad (1)$$

$$\frac{1 + \kappa^2 \lambda}{1 - a \kappa^2 + \kappa^2 \lambda} = m, \qquad (2)$$

where κ is the ratio of radii of the components.

If it be thought desirable to include the possibility of a flattening of the disks, we may assume, as a means of making a first approximation to the general effect of such deformation, that the bodies are similar ellipsoids of revolution and designate by q the common ratio of the semi-major to the semi-minor axis, whereupon equation (2) must be replaced by

$$q \frac{1 + \kappa^2 \lambda}{1 - a \kappa^2 + \kappa^2 \lambda} = m. \qquad (2a)$$

(Cf. this JOURNAL, **7**, 13, where $a\ \kappa^2$ should be stricken from the numerator of (e).)

From (1) and (2a) we find readily

$$\frac{a \kappa^2 \lambda}{1 + \kappa^2 \lambda} = (m - c\, q)/m, \qquad (3)$$

and
$$\frac{a\,\kappa^2}{1+\kappa^2\lambda}=(m-q)/m, \tag{4}$$
whence, dividing, we get
$$\lambda=(m-c\,q)/(m-q). \tag{5}$$

Neglecting the flattening provisionally, *i. e.* putting $q=1$, (5) gives, when the foregoing values of c and m are substituted,
$$\lambda=0.7865.$$

By making some easy transformations and reductions, we find:
$$\frac{m-q}{c\,q}\leqq\kappa^2\leqq\frac{q}{m-c\,q}. \tag{6}$$
From this, we have also,
$$\frac{m-q}{c\,q}\leqq\frac{q}{m-c\,q},$$
and finally
$$q\geqq\frac{m}{c+1}.$$

Substituting now the former values of m and c, we obtain
$$q\geqq 0.787.$$

It does not therefore appear to be necessary to assume the existence of a flattening for U Pegasi, such as was shown to be necessary in my "Dissertation on β Lyrae," p. 30, for the latter star.

Taking again the value of q as unity, and substituting in (6) we find:
$$0.6014\leqq\kappa^2\leqq 1.845, \text{ or } 0.7755\leqq\kappa\leqq 1.358.$$

The following test values distributed linearly over this interval were, therefore, selected for criteria to an approximation to κ:
$$0.80,\quad 0.85,\quad 1.00,\quad 1.15,\quad \text{and}\quad 1.35,$$
and for each of these values a light curve was computed by the method and with the results given below.

Using the portion of the light curve lying within 1.5 hours before and after Min. I., and the notation (see Fig. 1) and equations developed in my dissertation and published in the ASTROPHYSICAL JOURNAL for January 1898, I have to compute the

values of M and H from the data furnished by the light curve, and then for $\kappa < 1$, to solve the transcendental equations:

$$\begin{cases} M = \phi + \kappa^2 \phi'' - \kappa \sin (\phi'' + \phi) \\ H = \kappa^2 \phi' - \phi + \kappa \sin (\phi' - \phi), \end{cases} \tag{7}$$

and for $\kappa > 1$,

$$\begin{cases} M = \phi + \kappa^2 \phi'' - \kappa \sin (\phi' + \phi) \\ H = \phi_1 - \kappa^2 \phi'' + \kappa \sin (\phi_1 - \phi'') \end{cases} \tag{8}$$

for ϕ and ϕ'', and when $\kappa = 1$,

$$M = 2\,\phi - \kappa \sin 2\,\phi = 2\,\phi - \sin 2\,\phi \text{ (H being here zero).} \tag{8a}$$

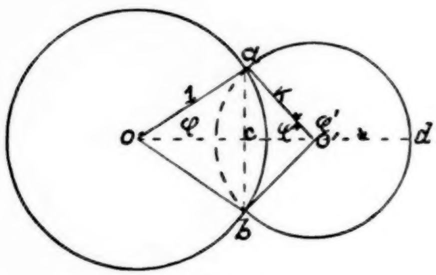


Fig. 1.

These solutions may be made most conveniently by means of tables giving the values of M and H for suitably chosen values of ϕ and ϕ', from which approximate values of ϕ and ϕ' may be interpolated, which may then be corrected by suitable differential formulæ.

Having thus obtained the value of ϕ for a number of points on the light curve (15 were used), the corresponding radii vectors ρ of the apparent orbit were computed by means of

$$\rho = \frac{\kappa \sin (\phi' + \phi)}{\sin \phi}, \quad \sin \phi' = \frac{\sin \phi}{\kappa}$$

for each test value of κ.

We then readily obtain the relation

$$\rho^2 = r^2 \sin^2 \beta + r^2 \cos^2 i \cos^2 \beta$$

Where β is the longitude in the apparent orbit reckoned from Min. I, r is the radius vector in the true orbit and i the inclination.

Putting:

$$x = r^2 \text{ and } y = r^2 \cos^2 i,$$

we have from the above relation:

$$\rho^2 = x \sin^2 \beta + y \cos^2 \beta. \quad (\beta = \mu t = 40^\circ \times t, \ t \text{ in hrs. from Min. I}).$$

In this we shall have the values of ρ^2 and β for the chosen points, and, solved by least squares, the equations furnish the most probable values of x and y, and, through these, of r and i.

The mean values and probable errors for each of the assumptions for κ are: For $\kappa = 0.80$, $r = 1.6636 \pm 0.0485$; for $\kappa = 0.85$, $r = 1.7512 \pm 0.0494$, and for $\kappa = 1.00$, $r = 1.9341 \pm 0.0535$. The individual determinations of $\cos^2 i$ are not given here, but the corresponding means and probable errors are, for the respective cases:

$$\cos^2 i = +0.0275 \pm 0.0069; \ = +0.0482 \pm 0.0072;$$
$$= +0.0547 \pm 0.0074.$$

The difference of the probable errors is not great in any case, but both r and $\cos^2 i$ agree in their testimony favoring the smallest value of κ as being the most probable. Assuming this value of κ however, a physical peculiarity, though not an impossibility, is met in the circumstance that the most probable distance of centers (1.6634) is considerably less than the sum of the radii ($= 1.8$), *i. e.*, the masses must interpenetrate, and consequently form a single body (Poincaré's apiod).

The probable errors not differing by enough to enable them to pronounce with sufficient emphasis for any one of the hypotheses, it seemed desirable to approach the problem also indirectly to see whether the conclusions will be the same as those given by this direct solution. That the foregoing discussion, however, indicates conclusively that the correct value of κ is smaller than 0.85, there can be no doubt.

INDIRECT SOLUTION.

The mode of procedure here is to read from the light curve, for suitably chosen epochs, the instantaneous brightnesses in stellar magnitudes, to form the differences between these bright-

nesses and the maximum brightness, to convert these differences, by means of the Pogson scale, into their equivalent light ratios, to compare these ratios with the corresponding ratios, computed from certain assumed elements, and finally, after finding sufficiently close approximations to the correct values of the elements, to adjust these differences in the sense computation minus observation, by the method of least squares.

Letting J' and J'' denote the instantaneous brightnesses in the neighborhood of Min. I. and Min. II., respectively, and M', H', M'' and H'', the corresponding values of the M and H defined by equations (12), it will be seen by referring to my article on β Lyrae, in the January ASTROPHYSICAL JOURNAL, that

$$1-J'=\frac{M'}{\pi(1+\lambda\kappa^2)}\,; \quad 1-J''=\frac{\lambda M''}{\pi(1+\lambda\kappa^2)}\,; \tag{10}$$

and hence there is an obvious advantage in adjusting $1-J'$ and $1-J''$ instead of J' and J''. The former quantities were therefore used throughout the reductions.

The equations for computing M', or M'' are:

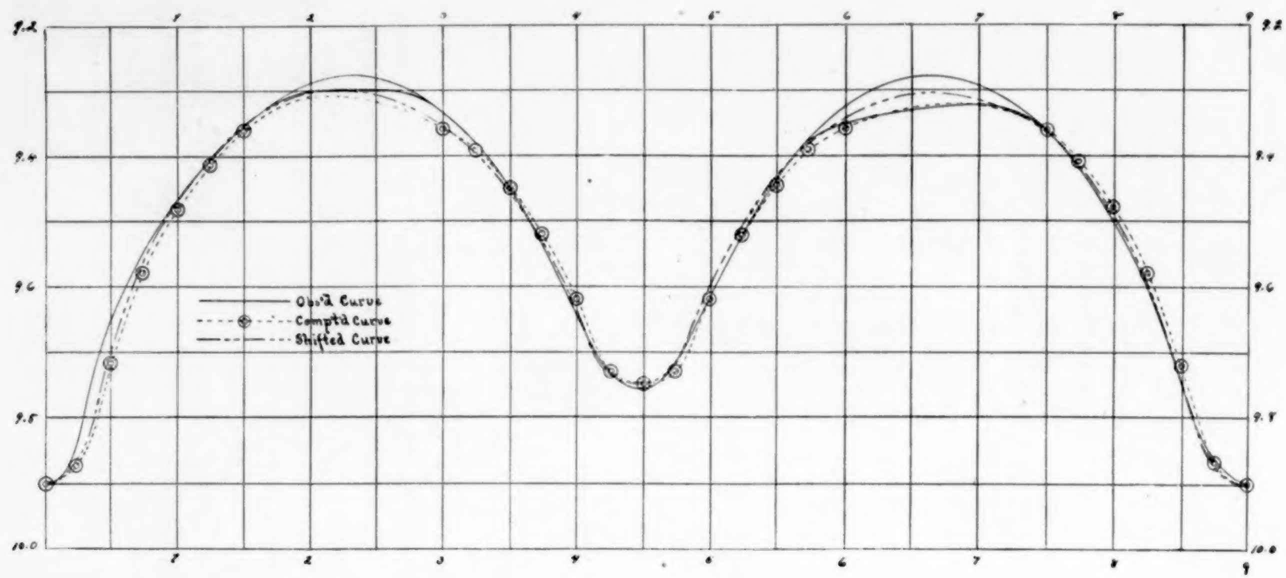
$$\left\{\begin{array}{l} (a)\ \beta=40^\circ\times t. \\ (b)\ \rho=r\sqrt{\sin^2\beta+\cos^2 i\cos^2\beta}.\ \text{If } i=\frac{\pi}{2}-i' \text{ is near } \frac{\pi}{2},\ i' \text{ is small and} \\ (c)\ \rho=r\sqrt{\sin^2\beta+i'^2\cos\beta}.\ \text{If } i'=0,\ \rho=r\sin\beta. \\ (d)\ \cos\phi=\dfrac{1+\rho^2-\kappa^2}{2\rho}. \\ (e)\ \sin\phi'=\dfrac{1}{\kappa}\sin\phi. \\ (f)^*\ M',\text{ or } M''=\phi+\kappa^2\phi''-\kappa\sin(\phi+\phi'')=\phi+\kappa^2\phi''-\rho\sin\phi. \end{array}\right. \tag{11}$$

Guided by the results of the direct solution, certain values were assumed for r, κ, q, λ and i', and a light curve was computed. Arbitrary but small changes were then made in each of the elements, each time being guided, of course, by the results of the foregoing assumptions, until, in all, about twenty light curves were computed. The values $r=1.7816$, $\kappa=0.7785$,

* N. B.—If it be desired to introduce the effect of flattening, we have:

$$M=\phi+\kappa^2\phi''-\sin\rho'\phi,\ \text{where } \rho'=\frac{1}{f}\rho \text{ and } \frac{1}{f}=\sqrt{\sin^2\beta+q^2\cos^2\beta}.$$

PLATE VI.



$\lambda = 0.7748$, $q = 1.02$ and $i' = 0$, gave quite a satisfactory curve, so satisfactory as to seem to warrant the use of a least square adjustment. The resulting corrections contained discordances among themselves and contraventions of fundamental physical laws to so great an extent as to cast entire discredit on the value of the least square adjustment. Several attempts were made to adjust the residuals furnished by other sets of elements with no better outcome.

Making a slight shift in the epoch of Min. I, which Professor Pickering has informed me personally to be allowable in consideration of the rather scanty observational data available for its determination, the close conformity of the computed with the *mean* observed curve may be seen from this table:

COMPARISON OF COMPUTED WITH OBSERVED CURVE.

t	J_o	J_c	ΔJ_{o-c}	J_o	J_c	ΔJ_{o-c}
	m.	m.	m.	m.	m.	m.
1.50	9.35	9.36	− 0.01	9.34	9.36	− 0.02
1.25	9.41	9.41	0.00	9.37	9.39	− 0.02
1.00	9.48	9.48	0.00	9.43	9.45	− 0.02
.75	9.58	9.58	0.00	9.52	9.52	0 00
.50	9.70	9.72	0.02	9.62	9.62	0.00
.25	9.84	9.87	0.03	9.72	9.73	− 0.01
0	9.90	9.90	0.00	9.75	9.75	0.00
Average deviations			= 0.009			= 0.01

The closeness of the correspondence of the computed with the *actual*, not *mean*, observed curve may be judged by reference to the detailed discussion contained in the *Bulletin* referred to at the outset, and is seen by comparing the shifted with the observed curve on the accompanying plate. I do not believe, after a protracted and rather tedious study of the star, that a better theoretical representation of U Pegasi's light curve is possible in the present *status* of the observational material. It seems to me, moreover, that the following results are pretty clearly indicated:

1. The light curve of U Pegasi given in *Harvard College Observatory Circular* No. 23, is satisfactorily represented by the satellite theory.

2. The distancc of centers does not materially differ from the sum of the radii of the components, suggesting the probable existence of the "apiodal" form of Poincaré.

3. The smaller companion is about 0.77 as bright as the larger, and the ratio of radii is approximately 1:0.78.

4. The inclination of the orbit is very nearly 90°, and the disk of one or both bodies, if separate, is slightly flattened.

5. The accuracy of present observations does not suffice to determine the elements of the "system" completely, since the foregoing discussion shows the residuals to be incapable of adjustment by least squares.

6. The manner of rise and fall of the observed curve after and before the minima, which portions of the curve were determined with especial care, fails to confirm one's first impression on examining the curve, viz., that the components are separated enough to remain apart for an appreciable time at the maxima. The difference between the durations of uniform brightness at the maxima, as shown by the curve, would seem to indicate a considerable orbital eccentricity, whereas the small distance of centers nullifies the possibility of its existence. It, therefore, seems desirable to direct attention to the importance of a careful photometric study of U Pegasi's light curve near the maxima, with a view to ascertaining whether or not the form of this curve near these epochs is real.

It may be objected that the inclusion of points in the vicinity of the maxima might exercise a modifying influence on the conclusions of this paper. A very little reflection will make it clear, when we compare the computed with the observed curve, that including such points can have no such influence whatever. The points selected were taken from those parts of the curve where the observations were most accordant, and where the accompanying description indicated that most care had been taken to eliminate errors of various sorts. To have included more points would only have rendered the computations more laborious and less readily comprehensible.

THE K LINES OF β AURIGAE.[1]

By ANTONIA C. MAURY.

A SERIES of two hundred photographs of the spectroscopic binary β Aurigae, obtained at Harvard Observatory in the work of the Henry Draper Memorial, shows a periodic change in the intensity of the K lines of the combined spectra.

The components of the binary revolve in a period of $3^d\ 23^h\ 37^m$ approximately, and with a combined velocity in the line of sight of 240^{km} a second. The distance between their centers, supposing the line of sight to lie in the plane of the orbit, is only about eight million miles. When the revolving stars are traveling at right angles to the line of sight, the lines of the combined spectrum appear single, but when one star is approaching and the other receding, the spectral lines are seen double, the components belonging to the approaching star being shifted toward the violet and those of the star receding, toward the red. The lines are accordingly double on every alternate night, and at intervals of two nights the relative position of the stars is reversed.

The photographs were taken with the 11-inch Draper telescope, two objective prisms being used in the case of 120 photographs, and three or four prisms for the eighty remaining, The series extends over a period of nine years, from 1889–90 to 1897–8, the photographs having been taken during from two to five of the winter months of each year, excepting 1896–7. These observations sometimes began as early as October and sometimes ended as late as April.

A detailed examination of the plates shows that the relative intensity of the K lines of the component stars is reversed each year as compared with the year preceding. The following table shows the results obtained. The first column gives the year of the observations, the second the number of plates taken, the third

[1] Read at the Harvard Conference, August 20, 1898.

the percentage of these in which the K line of one star, which we may call A, appeared the more intense; the fourth the percentage in which the K line of star B appeared more intense, and the fifth the percentage showing the K lines equal.

ALTERNATION IN INTENSITY OF K LINES.

Year	Number of plates	Stronger K line		K lines equal
		A	B	
1889–90......	23	70	17	13
1890–91.....	72	10	68	22
1891–92......	29	86	7	7
1892–93......	13	8	77	15
1893–94......	11	46	18	36
1894–95......	24	13	58	29
1895–96......	9	89	11	0
1897–98......	23	83	0	17

A few photographs showed a slight change in the intensity of the components of the double $H\gamma$ and $H\delta$, and the line of wavelength 4481.4, which is the most conspicuous of the fainter lines. This appeared to correspond with the variation in the K lines, but was too slight to be satisfactorily verified. It does not, however, seem unlikely that the spectra as a whole may vary, since the K line is the line of first type spectra best adapted to show slight changes, the lines of hydrogen being too wide and hazy, and the remaining lines too faint.

In the case of the spectroscopic binary μ' Scorpii it was observed by Mr. Bailey that the difference in the intensity of the lines of the component spectra appeared to change as if due to a variation in the light of one of the components.[1]

It does not seem probable that the apparent change is due to difference in the quality of the plates. Here both spectra are of the Orion type and the variation appeared in the hydrogen lines and lines peculiar to the Orion type.

Photographs of ζ Ursae Majoris, like β Aurigae, of the first type, give also interesting results. Twenty-two plates, taken

[1] *Harvard College Observatory Circular* No. 11, August 31, 1896.

between March 1887 and June 1890 show the line toward violet to be in most cases the more intense; while in nearly all the seventy-seven plates taken between May 1891 and July 1896 the line toward red is more intense. As the period of ζ Ursae Majoris is as yet undetermined, it is not known whether this indicates an actual reversal of intensity, as in β Aurigae, or whether the component stars have reversed their relative position.

The components of β Aurigae are probably nearly or quite equal in mass, and their spectra are closely similar. The most probable theory would seem to be that the revolving stars induce in one another reciprocal variability. If the period of this variability be two years it would represent about 180 revolutions. The components are conjectured to have each a probable mass of 1.25 times that of the Sun, and the probable distance between their centers being only about eight million miles, their influence on one another, electromagnetic or tidal, might be very great.

It is to be hoped that more definite results from the other spectroscopic binaries may show whether or not their components are in general variable.

NOTE.

It was stated at the Conference that in the double spectrum of β Aurigae the K of the line star approaching in the line of sight appeared wider than that of the star receding. From a later examination of the plates it seems probable that the greater width observed in the K line of the spectrum lying toward the violet may be due to a faint line of the superposed spectrum combining with this K line. It was previously supposed that the line referred to was too faint to alter the appearance of the K line, but it has since been found that the observed effect can be in part imitated by superposing two plates in which the spectra are single. It seems probable, though not quite certain, that this may explain the observed appearance.

OBSERVATIONS ON THE ABSORPTION AND EMISSION OF AQUEOUS VAPOR AND CARBON DIOXIDE IN THE INFRA-RED SPECTRUM.

By H. Rubens and E. Aschkinass.[1]

The researches of Langley[2] show that the energy in the infra-red spectrum decreases very rapidly from wave-length $2^{\mu}.7$ onward, and that measurable amounts of energy occur only at a few places beyond the wave-length $\lambda = 5^{\mu}$. The cause of this falling off in energy, which is very marked as compared with that in terrestrial sources of light, was recognized by Langley in the absorption by the Earth's atmosphere. In so far as it was not already established by Langley's own experiments, this view has been fully confirmed by the researches of Ångström[3] and Paschen.[4] Accordingly, there can be no doubt that aqueous vapor and carbon dioxide possess a very strong absorptive power in the spectral region in question, and that our atmosphere contains a sufficient amount of these gases to reduce the intensity of the solar rays practically to zero in most of these parts of the spectrum.

One of us, in conjunction with E. F. Nichols,[5] has recently shown that aqueous vapor and carbon dioxide exert only a very slight absorption upon the rather homogeneous bundle of rays of a mean wave-length of $24^{\mu}.4$, which can be separated from the total emission from a source of radiation by repeated reflection from surfaces of fluor-spar. It therefore did not seem impossible that the presence of these rays of wave-length 24^{μ} in the solar spectrum beyond the above-mentioned region of intense absorption by these gases might be demonstrated.

[1] Translated from *Wiedemann's Annalen*, **64**, 1898.

[2] Langley, *Phil. Mag.* (5), **26**, 505, 1888.

[3] Ångström, *Bihang till K. Svenska Vet. Akad. Handlingar*, **15**, Afd. 1, Nr. 9, 1889.

[4] Paschen, *Wied. Ann.*, **53**, 341, 1894.

[5] H. Rubens and E. F. Nichols, *Wied. Ann.*, **60**, 418, 1897.

That the earlier observers did not succeed in detecting these rays is sufficiently explained by the fact that they worked with prisms of fluorite and rock salt — substances through which these rays do not pass.

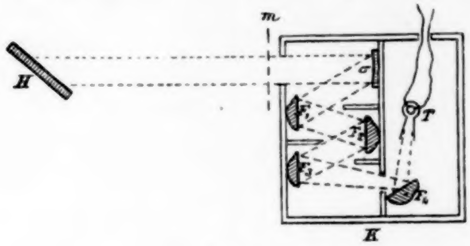


FIG. 1.

In answering the question as to the presence of these rays in the solar rays that reach us, we made the following experiment: We caused the solar rays reflected from the front silvered surface H of a heliostat mirror (Fig. 1) to undergo four reflections on the fluor-spar surfaces F_1 to F_4, after they had been rendered slightly convergent by the concave mirror σ. A linear thermopile, constructed by one of us,[1] served as the measuring instrument, in connection with a sensitive galvanometer protected against magnetic disturbances. The sensitiveness of the thermopile, which in these experiments was provided with a cone of 2 square centimeters' aperture, is approximately indicated by the fact that the radiation of a candle at 2 meters distance produced a throw of about 400^{mm} on the scale, on which fractions of a millimeter could be readily perceived. To avoid disturbances by currents of air and diffuse rays the mirror σ as well as the four fluor-spar surfaces and the thermopile were placed in a box K, in which screens were set in suitable places. The observer at the galvanometer could cause the heat-rays to enter the box by drawing up with a cord the glass screen m which was in the path of the rays.

The result of the experiment was a negative one. We did

[1] A full description of this thermopile may be found in *Z. f. Instrum.*, March 1898, p. 65.

not succeed in obtaining measurable deflections on drawing up the glass screen. But when we sent into the box the rays from a zirconium burner, rendered parallel by a concave mirror, instead of the solar rays, we observed a galvanometer throw of more than 200^{mm}, which wholly subsided when a rock salt plate of 5^{mm} thickness was inserted in the path of the rays, thus proving the accurate adjustment of the fluor-spar surfaces, and the considerably high sensitiveness of the apparatus.

We therefore held it to be not improbable that the residual rays of the fluor-spar, as well as the greatest part of the infra-red spectrum thus far investigated, were absorbed in the atmosphere, and it seemed desirable to repeat the earlier experiments on the absorption of carbon dioxide and aqueous vapor.

For this purpose we conducted a stream of dry carbon dioxide into the box *K* through a lateral aperture. The extinction of a burning match indicated that the air had been entirely displaced. In this way the rays from the zirconium burner were made to traverse a layer of carbon dioxide 60^{cm} long. In this experiment an air-tight chloride of silver plate was cemented in front of the aperture of the cone so that the carbon dioxide could not penetrate within. This precaution is necessary because otherwise the observed deflections would be altered in consequence of the slight thermal conductivity of the carbon dioxide, even without the effect of absorption.

The intensity indicated by the thermopile was, however, just the same as when the box was filled with air, so that no absorption of the heat rays by the carbon dioxide could be detected.

An appreciable absorptive effect of aqueous vapor was equally impossible to obtain when a stream of aqueous vapor was introduced in the path of the rays as above described.

Since, however, with this arrangement only a rather slight layer of the vapor is traversed by the rays, we varied the experiment as follows. A cast-iron tube, *E*, 40^{cm} long and 5^{cm} wide, was so arranged (Fig. 2) that the rays from the concave mirror *S* had to pass through its entire length. Steam could be conducted at pleasure into the tube *E* by heating the water in the

flask *F*, while the tube was maintained by three Bunsen burners at a temperature above 100° in order to avoid the condensation of the water vapor inside the tube. The drop-screen *m* was placed directly in front of the zirconium burner *Z* in order to

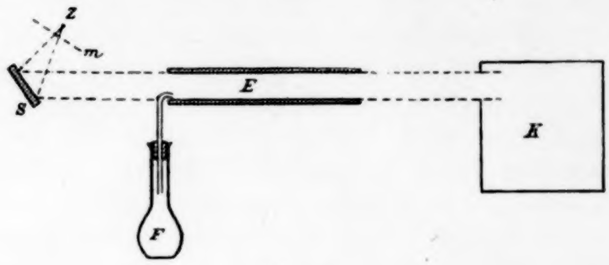


Fig. 2.

avoid the errors which would result from the heat emission of the hot tube. The distance of the opening of the tube *E* from the point of entrance of the rays into the box was made sufficient (about 25^{cm}) to make it impossible for the steam to enter the box. This provision is important, as otherwise the water vapor might condense on the reflecting surfaces. We have convinced ourselves by special tests that this did not occur.

It now appeared that the intensity of the residual rays from the fluor-spar was reduced to 31 per cent. of its original value as soon as the tube *E* was filled with water vapor. Hence, with the use of the longer layer, water vapor exhibited a clearly perceptible absorptive power for these rays sufficient to prevent their transmission by the Earth's atmosphere.

After this result had been gained, the next investigation was to see whether an emission of these rays from the heated water vapor could be proven. For this purpose the zirconium lamp was removed and the screen *m* placed again directly in front of the box *K*, without other change of the apparatus.

We then observed that when the tube *E* was filled with air a deflection of 20^{mm} occurred on drawing the screen *m*, chiefly due to the radiation from the tube itself; when the steam was conducted through the tube the deflection increased to 25^{mm}; hence

we obtained a distinct emission from the vapor in amount pretty nearly represented by the difference of the deflections.

It was to be expected after this experiment that the spectrum of the Bunsen burner would contain the residual rays of the fluor-spar. In fact, an ordinary triple burner placed in front of the opening of the box K gave deflections of 25^{mm}. A proof of the purity of the radiation was furnished by the insertion of a rock salt plate 5^{mm} thick in their path, with the result that the rays were wholly absorbed.

After we had further experimentally shown that the residual rays of quartz are present in considerable quantity in the radiation of the Bunsen burner, we resolved to undertake a systematic investigation of the spectral distribution of its radiation, as well as of the emission and absorption of aqueous vapor and carbon dioxide.

Paschen's[1] careful measurements of radiation and absorption of these gases include the region from immediately beyond the visible spectrum to about wave-length, $\lambda = 9^{\mu}$, a limit which could not be passed on account of the absorption by the fluorite prism which produced the spectrum. Our observations begin at this point and extend approximately to wave-length $\lambda = 20^{\mu}$.

EMISSION SPECTRA.

We began with the investigation of the emission of the Bunsen burner. The spectrum was produced by the large mirror spectrometer already often employed by one of us,[2] carrying a sylvin prism of 6^{cm} height, and $43° 57' 50''$ refracting angle, which almost entirely filled the objective of the reflecting telescope of $5.^{cm}5$ aperture and 56^{cm} focal length. The prism was maintained at minimum deviation by an automatic attachment. The dispersion was calculated according to the observations recently published by one of us in conjunction with Trowbridge.[3] According to these the spectrum extended over $1° 33'$ from the

[1] F. PASCHEN, *Wied. Ann.*, **51**, 1; **52**, 209; **53**, 335, 1894.

[2] A short description of the instrument may be found in *Wied. Ann.*, **54**, 270, 1894.

[3] H. RUBENS und A. TROWBRIDGE, *Wied. Ann.*, **60**, 724, 1897.

D lines to 9^{μ}, and over $3° 21'$ from 9^{μ} to 20^{μ}. Thus the conditions are distinctly more favorable in the latter region. Moreover, there are here no sharp absorption bands of sylvin like those observed at λ $3.^{\mu}20$ and λ $7^{\mu}.08$, but the absorption begins at 13^{μ} and increases very slowly and steadily. According to a rough estimate, at λ 18^{μ} some 70 per cent., and at λ 20^{μ} some 30 per cent. of the incident radiation is transmitted by the prism.

As in the previous experiments, the observations of energy were made with a linear thermopile constructed for measurements in the spectrum. The fifteen odd junctions, which were in a vertical line, were cut out by a number of rectangular diaphragms, the smallest of which was $0^{mm}.6$ wide and close to the thermopile. A bright sheet of copper was attached directly behind the thermopile, in order to reflect back upon the elements a part of the energy that had escaped between them. In the spectral region concerned the reflecting power of copper is sufficiently constant to prevent errors in the distribution of the energy from the use of the copper mirror.[1] Three slits were made in the copper to permit optical settings. The theoretical sensitiveness of the thermopile, made from wires of iron and "constantan" of $0.^{mm}1$ thickness, is calculated to be $15 \times 53 = 800 \times 10^{-6}$ volts per centigrade degree. Its internal resistance amounted to about seven ohms, the external resistance of the circuit (galvanometer and connecting wires) to little over five ohms. The current sensitiveness usually employed was about 3.3×10^{-10} amperes per millimeter of deflection. It follows from these data that a rise of temperature of the odd junctions of 5.9×10^{-6} centigrade degrees corresponds to 1^{mm} of galvanometer deflection. With this sensitiveness the constancy of the zero point, particularly in the evening hours, was very satisfactory, and the consequent high accuracy of the measurements made it possible to greatly reduce the number of single observations and the duration of the series of experiments. This was of special importance in measurements of absorption in which the constancy of the source of heat during the series of measurements had to be

[1] This is known from unpublished observations in this physical laboratory.

assumed. In consequence of the small capacity for heat of the thermopile, the warming and cooling of the junctions was effected in a few seconds, so that the instrument behaved like a bolometer on raising and dropping the drop-screen.

The radiation was emitted by four Bunsen triple burners set up in a row in the prolongation of the axis of the collimator. A plane mirror, silvered on the front surface, placed behind the burners, practically doubled the number of radiating flames and produced a considerable increase in the energy.

One of the most important sources of error, which greatly increases the difficulty of measuring in the region of long wave-lengths, is the impurity of the spectrum, due to stray radiations. All except a minute fraction of these stray radiations belong to the region of short waves ($1-7^{\mu}$) of great energy, and can therefore be suppressed, by the use of a fluor-spar screen instead of a glass screen, which transmits these rays, down to a very small part, some 6 or 7 per cent. due to reflection of the fluor-spar screen. It is true that this procedure is theoretically not quite so correct as that of double spectral dispersion, but it has the practical advantage of greater simplicity, and avoids the considerable losses of energy in the latter process. We have convinced ourselves by investigating the selective absorption of rock salt that both methods furnish like results within the limits of errors of observation. We have, therefore, chiefly employed a fluor-spar screen in the region beyond 12^{μ}.

Beyond the limit $\lambda = 18^{\mu}$ the use of a rock salt screen is permissible if of sufficient thickness. In this part of the spectrum we repeatedly used as screen a rock salt plate of 23^{mm} thickness, which transmitted 4.9 per cent. at 18^{μ}, and 0.1 per cent. at 19^{μ}.[1] The results when this screen was used showed no appreciable differences from those obtained with a fluor-spar screen.

For the sake of completeness and to test our arrangement of experiments, we also measured the region of short-waves in the emission spectrum of the Bunsen burner already investigated by

[1] *Cf.* H. RUBENS u. A. TROWBRIDGE, *loc. cit.*, p. 736.

Paschen, but we would distinctly state that, on account of the slight dispersion and the selective absorption of sylvin, the

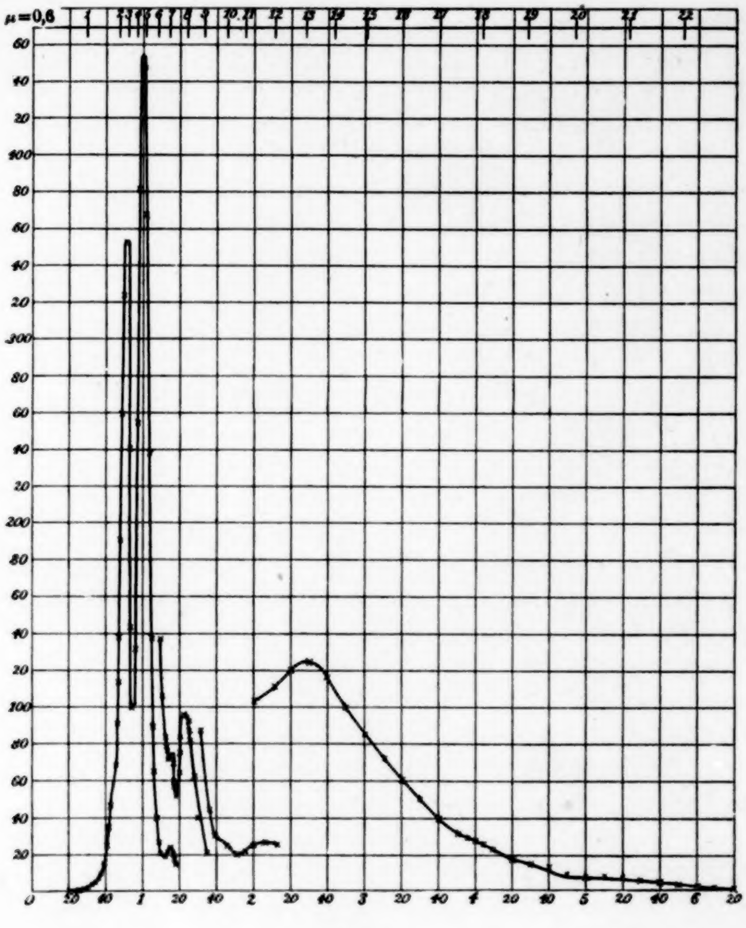


Fig. 3.

measures could not be such as to be comparable in accuracy with those of Paschen. The slit width was 0.^{mm}2, the width of the thermopile 0.^{mm}6 (see above). The results are shown graphically in Fig. 3. The ordinates represent the galvanometer deflec-

tions, the abscissas the differences of minimum deviations from those of the D line, and of wave-lengths. A closer examination of the energy curve shows the presence of all the stronger maxima of emission of water vapor and of carbon dioxide at the same positions where they were observed by Paschen in the dispersion spectrum of fluorite, with the exception of the elevation at $\lambda = 5^{\mu}.4$ which belongs to the emission spectrum of water vapor, and which is here wholly concealed by the strong emission band of carbon dioxide at $\lambda = 4^{\mu}.40$. With the width of slit employed the energy of the spectrum was sufficient for observation as far as $\lambda = 7.4$. At this point the bilateral slit was opened to $0.^{mm}4$, and then to $1^{mm}.0$, and with this width the measurements were continued respectively to $\lambda = 9.1$ and $\lambda = 12^{\mu}$, where a further opening of the slit to $5^{mm}.5$ was necessary. Accordingly the curve in Fig. 3 is in separate sections.

In the part of the curve of energy beyond $\lambda = 9^{\mu}$, here published for the first time, the emission apparently assumes a more continuous character. The curve shows at $\lambda = 10^{\mu}.7$ a minimum, at $\lambda = 13^{\mu}.1$ a faint maximum, and then approaches the axis of abscissas as an asymptote. We have not succeeded in resolving this broad band, reaching from $\lambda = 11^{\mu}$ to beyond $\lambda = 20^{\mu}$, into separate lines by narrowing the slit. The experiments with absorption communicated below teach, on the other hand, that we are here dealing with a large number of neighboring bands.

In order to determine what part the heated water vapor has in the region of long wave-lengths in the radiation of the Bunsen burner, we now placed a hydrogen flame before the slit of our spectroscope. In order to bring as thick a layer of water vapor as possible into radiation we had inclined the hydrogen flame at a very acute angle to the axis of the collimator. The radiation entering the slit was also intensified by use of a concave mirror. Fig. 4 shows the results of the observations which were again made with different widths of slit ($0^{mm}.5$ and $3^{mm}.5$), as is apparent from the jump in the curve. The first part of the curve contains the maximum of water vapor, lacking in Fig. 3, which is covered up by the emission band of carbon dioxide, at

$\lambda = 5^{\mu}.4$, and which was given by Paschen. Beyond $\lambda = 9^{\mu}$ the curve runs about as in Fig. 3.

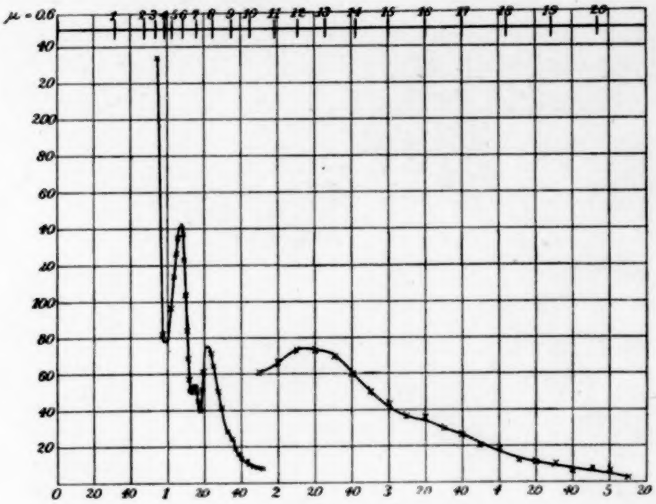


FIG. 4.

We investigated the emission spectrum of the heated carbon dioxide in the following manner. We placed (Fig. 5) before

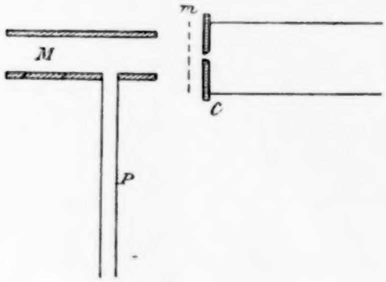


FIG. 5.

the spectrometer slit *C* a brass tube *M*, 25^{cm} long, and 4^{cm} wide, which was maintained at a high temperature by a triple burner. Into the side of this entered a platinum tube P, 14^{cm} long, and 8^{mm} in diameter, which was held at a bright red heat by a

second triple burner. A steady stream of dry carbon dioxide was conducted into this from a gasometer, and was thus brought to radiating. We satisfied ourselves by trials that no radiation from the burners or from the walls of the hot tube could enter into the spectrometer.

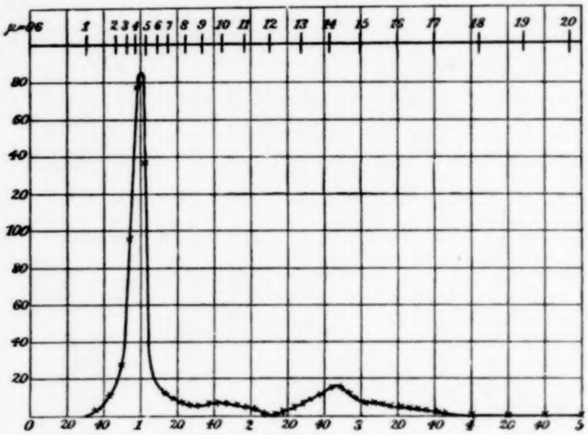


Fig. 6.

The curve in Fig. 6, which represents the results of our observations of the emission of hot carbon dioxide, shows that beside the previously known emission bands at $\lambda = 4^{\mu}.4$ and $\lambda = 2^{\mu}.7$, there is a third maximum with its greatest elevation at about $\lambda = 14^{\mu}.1$. The probable reason for its non-appearance in the emission curve of the Bunsen burner is because it is covered up by the considerably stronger maximum of water vapor lying near it.

ABSORPTION SPECTRA.

The above experiments on emission can for several reasons furnish only an incomplete picture of the spectral properties of the gases investigated. For one thing the observed energy of the radiation is so slight that beyond 9^{μ} in part a very wide slit (up to $5^{mm}.5$) had to be employed. The spectrum is, therefore, very impure, and the possibility is excluded of observing details,

which extend over only a few minutes of arc. Further, the position of the maxima and minima are affected by three minor circumstances which can be only partially eliminated. These are: first, the temperature of the source of radiation, by which, as is well known, the short waves are relatively the more favored, as the temperature is elevated; secondly, the dispersion, and thirdly, the absorption of the prism. We have, therefore, refrained from drawing extensive conclusions from the above observations of emission, and only briefly communicate them as furnishing a good control on the measurements of absorption now to follow.

In these measurements the source was a zirconium burner whose radiations were concentrated on the slit of the spectrometer by one or more concave mirrors. A layer of water vapor or carbon dioxide could be suitably inserted in the path of the rays. Quite different arrangements were necessary in the two cases on account of the different characteristics of the two gases.

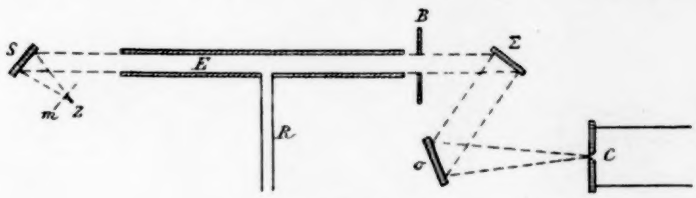


FIG. 7.

Fig. 7 shows the arrangement employed in investigating the absorption of aqueous vapor. The rays from the zirconium mantle *Z* are rendered parallel by the concave mirror *S*, and then traverse the cast iron tube *E*, 75^{cm} long, which is heated above $100°$ by four Bunsen burners beneath it, and can be fed with a permanent stream of vapor through the brass tube *R* entering at the side. Directly behind the iron tube is a circular diaphragm *B* which excludes the radiation of the wall of the tube, and a plane mirror Σ which reflects the rays emerging from the tube to the concave mirror and by which they are concentrated upon the slit of the spectrometer. This arrangement,

resembling in many points that used by Paschen, permitted us to make observations in quick succession, if alternately air and water vapor occupied the tube E, so that we could obtain the absorption of a layer of vapor 75^{cm} thick independently of the distribution of energy in the spectrum, and without putting too high demands upon the constancy of the source of light.

The arrangement employed for observing the absorption spectrum of carbon dioxide was as follows. (Fig. 8.) A zirconium burner Z was placed horizontally a few centimeters above a

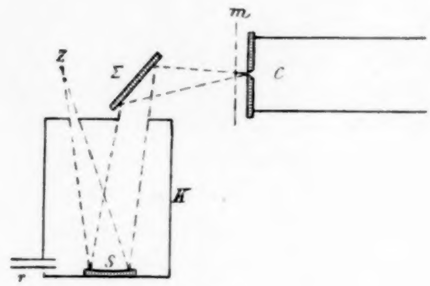


FIG. 8.

wooden box K, 30^{cm} deep, 12^{cm} wide and 30^{cm} long. The rays passed through a circular aperture in the top of the box to a concave mirror S on the bottom of the box, which reflected them through another hole in the top to a plane mirror Σ. The focal length of the mirror S was such that the rays reflected from Σ gave a sharp image of the zirconium mantle in the plane of the slit. A glass tube r entered the box near the bottom, through which a stream of dry carbon dioxide could be continuously led into the box. All of the joints and cracks in the box were carefully filled air-tight with wax so that after displacing the air the carbon dioxide could escape only through the two apertures in the top. The mean path traversed within the box by the rays was about 65^{cm}. As the preliminary experiments showed that the absorption of carbon dioxide beyond 9^{μ} was limited to a very small region, it was possible to observe three energy curves in succession, the first when the box was filled with air, the second

when filled with dry carbon dioxide, and the third, which served as a control, under the same conditions as the first. The carbon dioxide in the box was replaced by the air in the room by attaching a water air-pump to the glass tube which exhausted the carbon dioxide and the air entered the apertures in the top of the box.

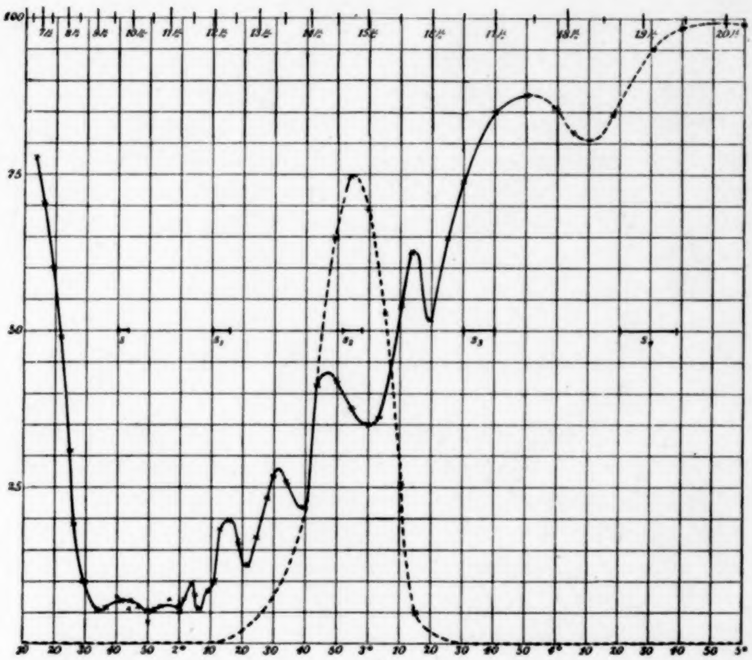


Fig. 9.

The results of our observations of absorption are graphically shown in Fig. 9. On account of the uncommonly strong energy of the source of light, the observations could be made with quite a narrow slit. All the measures on carbon dioxide were made with a slit width of 1^{mm}; in those on water vapor the width varied from $0^{mm}.5$ to $3^{mm}.0$, being $0^{mm}.5$ between 7^{μ} and 11^{μ}, $0^{mm}.8$ between 11^{μ} and 14^{μ}, $1^{mm}.1$ between 14^{μ} and 16^{μ}, $1^{mm}.7$

between 16^{μ} and $17^{\mu}.6$, and $3^{mm}.0$ between $17^{\mu}.5$ and 20^{μ}, while the thermopile was without change $0^{mm}.6$ wide. The apparent width of the slit in minutes of arc is represented in Fig. 9 by the length of the lines $s, s_1 \ldots\ldots s_4$. At $\lambda = 17^{\mu}.5$ the deflections were respectively 22^{mm} and $2^{mm}.6$ with and without the introduction of the layer of water vapor. On account of the lesser accuracy we have therefore indicated the absorption from here on by a dotted curve.

In the curves of Fig. 9, as also previously in the curves of emission, the angles of deviation a, or more correctly their differences from the minimum deviation of the D line, $a_D - a_\lambda$, are entered as abscissas. The ordinates represent the amount of the absorbed energy, the incident energy being called 100. The scale at the upper edge of the figure gives the wave-lengths corresponding to the different angles of deviation.

Water vapor shows only faint absorption in the spectral region between $\lambda = 9^{\mu}$ and $\lambda = 11^{\mu}$, as compared with shorter and longer waved parts of the infra-red. From this follows the minimum observed in the emission at $\lambda = 10^{\mu}.7$. Beyond 11^{μ} the absorption begins to increase and becomes almost total at $\lambda = 20^{\mu}$, whereby the maximum observed in the emission at $\lambda = 13^{\mu}.1$ is explained. In the region between 11^{μ} and 18^{μ} water vapor possesses six conspicuous maxima of absorption, which have according to our observations the wave-lengths $\lambda = 11^{\mu}.6$, $12^{\mu}.4$, $13^{\mu}.4$, $14^{\mu}.3$, $15^{\mu}.7$, and $17^{\mu}.5$.

It is highly probable that in the region of shorter wave-lengths between 9^{μ} and 11^{μ} a number of such absorption bands are also present, of which two are suggested by the curve, but here the dispersion of our sylvin prism is plainly no longer sufficient for their complete resolution. The same is true for the portion of spectrum between 7^{μ} and 9^{μ} which we added for the purpose of connection with Paschen's observations. His observations give for a layer of water vapor 7^{cm} thick a continuous falling off in the absorption from 82.3 per cent. down to 8.0 per cent. between wave-lengths $6^{\mu}.53$ and $8^{\mu}.26$, thus qualitatively according well with our measures. A quantitative comparison of our

results with those of Paschen seems however to be impossible, since the law of absorption cannot be applied to spectra which consist of small separate absorption bands whose separation cannot be accomplished on account of the impurity of the spectrum. This follows from Paschen's own observations, for he finds for example at λ $7^{\mu}.87$ 12.5 per cent. of absorption for layer of water vapor 7^{cm} thick,[1] and 13 per cent. for a layer 33^{cm} thick.[2] Ångström has also made similar observations in the study of the absorption spectrum of other gases.

Our experiments carried out as described above on the absorption spectrum carbon dioxide very soon showed that we were dealing with a single absorption band whose maximum lies near $\lambda = 14^{\mu}.7$. However, the thickness of the absorbing stratum of carbon dioxide proved to be too great to give a distinct picture of the way the absorption runs in the spectrum, since between 14^{μ} and $15^{\mu}.5$ an almost complete extinction of the energy occurred. We therefore filled the box only to about one-third of its depth with carbon dioxide and then obtained the absorption spectrum represented in the dotted curve of Fig. 9. The whole region of absorption is limited to the interval from $12^{\mu}.5$ to 16^{μ}, with the maximum at $14^{\mu}.7$. Aside from this region not the slightest absorption could be detected between 8^{μ} and 20^{μ} even when the box was completely filled with carbon dioxide. The observed emission spectrum of carbon dioxide is thus easily explained. The maximum of the radiated energy is displaced toward the side of shorter waves in consequence of the three circumstances mentioned above and appears at $14^{\mu}.1$ (see Fig. 6).

The absorption band at $14^{\mu}.7$ is so sharp that it comes out distinctly in every energy curve in consequence of the carbon dioxide in the air of the room, while the absorption bands of water vapor cannot be observed in this way under an average humidity.

The observations now communicated show that the Earth's

[1] PASCHEN, *Wied. Ann.*, 52, 214, 1894.

[2] *Wied Ann.*, 51, 19, 1894.

atmosphere must be wholly opaque for the rays of wave-length 12^{μ} to 20^{μ} as well as for those of wave-length $24^{\mu}.4$. In fact Langley's observations on the spectrum of the Sun and Moon only extend to minimum deviations of his rock salt prism of about 36°, corresponding to an extreme wave-length of from 10^{μ} to 11^{μ}.

For practical meteorology the fact that the solar rays beyond $\lambda = 12^{\mu}$ are absorbed in the Earth's atmosphere is after all of slight importance, as the energy of these rays is very small in comparison with the total emission of the Sun.

PHYSICAL LABORATORY OF THE TECHNICAL HOCHSCHULE.
Charlottenburg, December 1897.

Minor Contributions and Notes

THE HARVARD CONFERENCE.

The selection of the Harvard College Observatory as the place of meeting for the Second Annual Conference of astronomers and astrophysicists doubtless had much to do with the highly successful outcome of the gathering. The numerous instruments, many of them operated by automatic devices, together with the unrivaled collection of celestial photographs, afforded the visitors opportunities for study not to be found elsewhere. The meetings were held in the drawing-room of the Director's residence, which was most hospitably thrown open for the occasion. At the conclusion of the first morning's session, the members of the conference were entertained at luncheon by Professor and Mrs. Pickering, and on the second day similar entertainment was provided at Memorial Hall by the President and Fellows of Harvard University. On the third day, after the adjournment of the regular sessions, a large party visited the Blue Hill Meteorological Observatory at the invitation of the proprietor, Mr. A. Lawrence Rotch. Ample opportunity was afforded between the sessions for the inspection of the laboratories and museums of Harvard University, while the members of the Observatory staff were always ready to assist visitors in their examination of the instruments and photographs so bountifully displayed.

The following persons were registered as attending the conference:

Mr. C. G. Abbott, Smithsonian Astrophysical Observatory, Washington, D. C.
Mr. W. H. Atwill, Harvard College Observatory, Cambridge, Mass.
Professor S. I. Bailey, Harvard College Observatory, Arequipa, Peru.
Professor E. E. Barnard, Yerkes Observatory, Williams Bay, Wis.
Mr. N. E. Bennett, Wilmington, O.
Mr. S. H. Brackett, St. Johnsbury, Vt.
Professor H. S. Carhart, University of Michigan, Ann Arbor, Mich.
Dr. F. J. Chase, Yale University, New Haven, Conn.
Mr. H. Helm Clayton, Blue Hill Meteorological Observatory, Hyde Park, Mass.
Professor W. H. Collins, Haverford College, Haverford, Pa.

Mr. H. R. Colson, Harvard College Observatory, Cambridge, Mass.
Professor George C. Comstock, Washburn Observatory, Madison, Wis.
Professor Charles R. Cross, Massachusetts Institute of Technology, Boston, Mass.
Professor A. E. Dolbear, Tufts College, Somerville, Mass.
Miss H. R. Donaghe, Morristown, N. J.
Professor C. L. Doolittle, Flower Observatory, Upper Darby, Pa.
Professor H. W. Du Bois, Central High School Observatory, Philadelphia, Pa.
Mr. J. A. Dunne, Harvard College Observatory, Cambridge, Mass.
Professor J. R. Eastman, U. S. Naval Observatory, Washington, D. C.
Mrs. I. W. Eddy, Harvard College Observatory, Cambridge, Mass.
Dr. W. S. Eichelberger, U. S. Naval Observatory, Washington, D. C.
Professor W. L. Elkin, Yale University Observatory, New Haven, Conn.
Mr. S. P. Fergusson, Blue Hill Meteorological Observatory, Hyde Park, Mass.
Professor R. A. Fessenden, Western University of Pennsylvania, Allegheny, Pa.
Mr. Edward P. Fleming, Harvard College Observatory, Cambridge, Mass.
Mrs. M. Fleming, Harvard College Observatory, Cambridge, Mass.
Professor A. S. Flint, Washburn Observatory, Madison, Wis.
Professor Edgar Frisby, U. S. Naval Observatory, Washington, D. C.
Mr. R. H. Frost, Harvard College Observatory, Cambridge, Mass.
Miss Caroline E. Furness, Vassar College Observatory, Poughkeepsie, N. Y.
Miss E. F. Gill, Harvard College Observatory, Cambridge, Mass.
Professor H. M. Goodwin, Massachusetts Institute of Technology, Boston, Mass.
Miss Ida Griffiths, Poughkeepsie, N. Y.
Rev. J. G. Hagen, Georgetown College Observatory, Georgetown, D. C.
Professor George E. Hale, Yerkes Observatory, Williams Bay, Wis.
Mr. J. F. Hayford, U. S. Coast and Geodetic Survey, Washington, D. C.
Miss Lillian Hodgdon, Harvard College Observatory, Cambridge, Mass.
Professor G. W. Hough, Dearborn Observatory, Evanston, Ill.
Professor Harold Jacoby, Columbia University, New York City.
Mr. E. S. King, Harvard College Observatory, Cambridge, Mass.
Mr. Lawrence La Forge, Cambridge, Mass.
Miss E. F. Leland, Harvard College Observatory, Cambridge, Mass.
Professor F. H. Loud, Colorado College, Colorado Springs, Colo.
Mr. Carl Lundin, Cambridgeport, Mass.
Dr. Alex. Macfarlane, Lehigh University, South Bethlehem, Pa.
Miss A. C. Maury, Harvard College Observatory, Cambridge, Mass.
Professor C. H. McLeod, McGill University, Montreal, Canada.
Professor Dayton C. Miller, Case School of Applied Science, Cleveland, O.
Professor E. W. Morley, Adelbert College, Cleveland, O.
Professor G. W. Myers, University of Illinois, Champaign, Ill.

Professor Simon Newcomb, Washington, D. C.
Mr. H. M. Parkhurst, Brooklyn, N. Y.
Professor H. M. Paul, U. S. Naval Observatory, Washington, D. C.
Professor B. O. Peirce, Cambridge, Mass.
Professor E. C. Pickering, Harvard College Observatory, Cambridge, Mass.
Mrs. E. C. Pickering, Harvard College Observatory, Cambridge, Mass.
Professor W. H. Pickering, Harvard College Observatory, Cambridge, Mass.
Professor Charles Lane Poor, Johns Hopkins University, Baltimore, Md.
Miss Mary Proctor, New York City, N. Y.
Rev. Alden W. Quimby, Berwyn, Pa.
Mr. F. G. Radelfinger, Nautical Almanac Office, Washington, D. C.
Mr. W. Maxwell Reed, Andover, Mass.
Mr. Charles H. Rockwell, The Observatory, Tarrytown, N. Y.
Mr. Jonathan T. Rorer, Central High School Observatory, Philadelphia, Pa.
Mr. A. Lawrence Rotch, Blue Hill Meteorological Observatory, Hyde Park, Mass.
Professor W. C. Sabine, Harvard University, Cambridge, Mass.
Mr. F. E. Seagrave, Private Observatory, Providence, R. I.
Professor Arthur Searle, Harvard College Observatory, Cambridge, Mass.
Professor A. N. Skinner, U. S. Naval Observatory, Washington, D. C.
Mr. Frederick Slocum, Ladd Observatory, Providence, R. I.
Professor M. B. Snyder, Central High School Observatory, Philadelphia, Pa.
Rev. John Stein, Leyden, Netherlands.
Miss M. C. Stevens. Harvard College Observatory, Cambridge, Mass.
Mr. Charles E. St. John, Oberlin, O,
Mr. A. E. Sweetland, Blue Hill Meteorological Observatory, Hyde Park, Mass.
Professor D. P. Todd, Amherst College Observatory, Amherst, Mass.
Professor Winslow Upton, Ladd Observatory, Providence, R. I.
Professor J. M. Van Vleck, Wesleyan University, Middletown, Conn.
Professor F. W. Very, Providence, R. I.
Mr. Robert De C. Ward, Harvard University, Cambridge, Mass.
Mr. Charles F. Warner, Cambridge Manual Training School, Cambridge, Mass.
Mr. W. R. Warner, Cleveland, O.
Professor A. G. Webster, Clark University, Worcester, Mass.
Professor O. C. Wendell, Harvard College Observatory, Cambridge, Mass.
Miss Sarah F. Whiting, Wellesley College, Wellesley, Mass.
Professor F. P. Whitman, Adelbert College, Cleveland, O.
Miss Mary W. Whitney, Vassar College Observatory, Poughkeepsie, N. Y.
Miss A. Winlock, Harvard College Observatory, Cambridge, Mass.
Miss L. Winlock, Harvard College Observatory, Cambridge, Mass.
Miss E. G. Wolffe, Harvard College Observatory, Cambridge, Mass.

Miss I. E. Woods, Harvard College Observatory, Cambridge, Mass.
Professor R. S. Woodward, Columbia University, New York City.
Mr. Paul S. Yendell, Dorchester, Mass.

As it is intended to publish in the November number of this JOURNAL abstracts of all the papers presented to the conference, no account of this part of the proceedings will be given here. Mention should be made, however, of certain actions of the conference which will not find a place in these proceedings.

In the Friday morning session, which was devoted to a discussion of various matters of general interest, the question of forming an astronomical and astrophysical society was considered, and referred to a committee, consisting of Professors Pickering, Newcomb, Comstock, Morley, and Hale. Before the committee was appointed it was resolved, by unanimous vote, that the annual conferences should be continued, either in their present form, or under the auspices of an organized society. The committee, in offering its report at the next session of the conference, recommended that a society be formed, and presented the first draft of a constitution. It also recommended that on the following Tuesday a meeting for the purpose of effecting a preliminary organization should be held by those who had previously signed a statement signifying their wish to become charter members of the society. The meeting was duly held at the Massachusetts Institute of Technology, sixty-one persons having signed the statement. After a brief discussion, the same committee of five, with power to add four to its number, was appointed to act as the first council of the society. The duties of the committee include the drafting of a constitution, the election of members to the society, arrangements for the next meeting, and other business of a similar nature.

At the Friday morning session of the conference some time was devoted to a discussion of the United States Naval Observatory. No action was taken at this time, but on Saturday the following resolution, offered by Professor Flint, was unanimously adopted:

Resolved, That a committee of three be appointed by the conference to consider the question of the proper organization and function of the United States Naval Observatory; to draw up resolutions expressing different representative views; to obtain signatures of astronomers and astrophysicists of the country; and to present the same in person to the Secretary of the Navy by January 1899, and to other authorities at their discretion.

Further, That said committee be instructed to coöperate with any other committees that may be appointed in this country to consider questions connected with the scientific functions of the national government; and to take such further action as may seem to said committee expedient.

The committee, appointed by ballot, consists of Professors Pickering, Comstock, and Hale. The American Association for the Advancement of Science at its meeting in Boston, subsequently appointed a committee for a similar purpose, consisting of Professors Pickering, Mendenhall, and Woodward.

The total solar eclipse of May 28, 1900, was also discussed by the conference, and the chairman was instructed to appoint a committee to coöperate with observers and to take such action as might be deemed necessary to secure the best results. Professors Pickering, Barnard, and Comstock were named. At a subsequent session of the conference, the committee recommended that another committee, consisting of Professors Newcomb, Barnard, Campbell, and Hale, be appointed to act in its place. This recommendation was adopted, and the new committee was given power to add to its number should this seem desirable.

The committee on the *Northern Durchmusterung*, appointed at the Yerkes Observatory conference, reported that satisfactory progress was being made in printing the new edition. Largely through the efforts of the committee, the new edition has been freely subscribed for by American astronomers.

The best method of filling vacant positions in astronomy and physics was discussed by Professor Pickering. It was arranged that he should act as a committee of the new society on this subject. Those desiring to obtain positions, or having vacant positions which they wish to fill, may therefore advantageously communicate with him.

The meeting of the American Association in Boston during the week following the adjournment of the conference practically amounted to an extension of the Harvard meetings, so far as the astronomical work of Section A was concerned. Professor Barnard's important address on Astronomical Photography, and the numerous interesting papers presented to the Section, added greatly to the value of the previous week's proceedings. The conference had already enjoyed the hospitality of the Institute of Technology, as Professor Cross had provided a stereopticon for an evening meeting held there at his invi-

tation. The continuity of the Cambridge and Boston meetings was thus almost unbroken, over a week being devoted to the discussion of astronomical and astrophysical topics. G. E. H.

PHOTOGRAPH OF "FLASH" SPECTRUM.

To the Editors of the ASTROPHYSICAL JOURNAL:

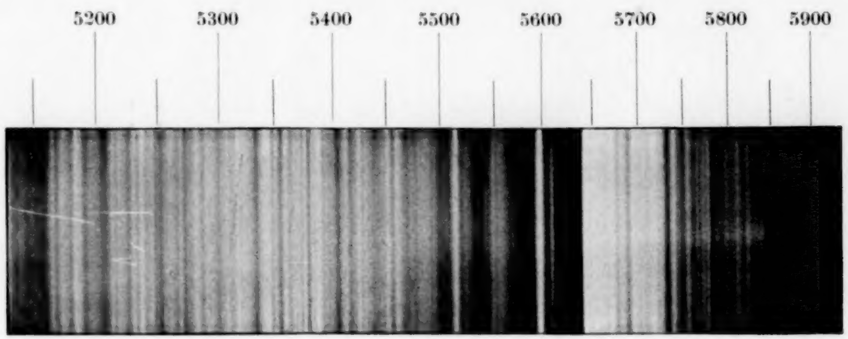
AS PROBABLY you have found out before now, there appears to be a mistake in the last sentence of the article on above, on p. 121 in your August issue. A comparison with Evershed's photograph in *Knowledge*, June 1898, shows that the two images of the prominence really belong to the lines H and K; the prominence being lofty enough to appear projecting beyond a part of the Moon's disk where nothing else is shown in the photograph. There appears also an image of the prominence formed by the $H\gamma$ line, in contact with the outer edge of the next conspicuous line toward the red. This latter line also has an image of the prominence as a very faint spot; and there may be others; but it is rather singular $H\beta$ has no image, seeing it is conspicuous in Evershed's spectrum.[1]

T. W. BACKHOUSE.

WEST HENDON HOUSE, Sunderland,
September 7, 1898.

[1] An examination of another photograph, recently received from Professor Naegamvala, shows that Mr. Backhouse is undoubtedly right. In this photograph the $H\beta$ image is also clearly shown.— EDS.

PLATE VII.



SPECTRUM OF 152 SCHJELLERUP.

PHOTOGRAPHED WITH A THREE PRISM SPECTROGRAPH ATTACHED TO THE FORTY-INCH YERKES TELESCOPE.